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Defining Framework for Elasticity Management of Radio Controllers in Cloud

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PREFACE

This Master of Science Thesis work has been done as part of the Master of Science Degree Programme in Information Technology at the Metropolia University of Applied Sciences, Helsinki, Finland.

This thesis work has been carried out in the Research and Development Department of Nokia Networks during years 2015 and 2016.

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Anand Radhakrishnan

ABSTRACT

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Cloud computing has come a long way over the last years and technologies using cloud computing are increasing at rates never experienced before. Cloud computing is attractive because of its efficiency, convenience and per-service business model. It does not come as a surprise when the telecom vendors of the world have realized this as a new source of revenue in the ever so demanding telecom business. Hence, initiatives are being taken to virtualize not only the latest technologies such as 5G, but also the existing technologies, namely 4G, 3G and 2G. In order to survive in a competitive and fast moving world, telecom equipment vendors have to differentiate the benefits that operators would get through this transition. And one of the most important benefits is ease of scalability. In a broad sense, scalability itself opens a new range of avenues where the operator can benefit from temporarily shutting down resources when usage is low and starting them up again when resource demand is on the rise. In order to cope with such requirements, there is a massive architectural change required in the software of legacy network elements before they can be moved to cloud.

This paper focuses on the elasticity management procedures in the second generation Base Station Controller in Telco Cloud. This is one of the most legacy technologies of the telecom network elements and therefore also the most difficult one in terms of transitioning to the cloud. There are many operators still utilizing the wide base of Global System for Mobile services and many other operators who plan to keep Global System for Mobile networks live for at least five more years. Moreover, half of the world's population, majority being in the developing countries, still uses basic cellular services on 2G networks. In the developed world, there are operators in Europe, who plan to shutdown 3G network services while leaving the 2G networks for Machine-to-Machine communication. Hence, there is a genuine customer need to virtualize such legacy network elements in the cloud.

Even though this thesis focuses on elasticity procedures for the 2nd generation Base Station Controller, the generic principles of graceful shutdown and radio network re-allocation discussed in this paper can also be applied to radio controllers of other technologies such as 3G and 4G.

Keywords	Base Station Controller, Cloud, VNF, Elasticity, VM, Telco, Scaling, Radio Controller, GSM, Radio network Re-allocation

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Abbreviations

TRX	Transceiver
CN	Core Network
BTS	Base Transceiver Station
RNW	Radio Network
MSS	Mobile Switching Server
MS	Mobile Station
UE	User Equipment
MGW	Media Gateway
SGSN	Serving GPRS Support Node
GPRS	General Packet Radio Service
IUA	ISDN User Adaptation
SCTP	Stream Control Transmission Protocol
M3UA	MTP Level 3 User Adaptation Layer
MTP	Message Transfer Part (SS7)

SS7	Signalling System No: 7
BSU	Base Station Controller Signalling Unit
ABDU	Abis Interface Data-Plane Unit
AIDU	A-interface Data-Plane Unit
PCU	Packet Control Unit
CMU	Central Management Unit
RMU	Radio Management Unit
VLAN	Virtual Local Area Network
IP	Internet Protocol
SCCP	Signalling Connection Control Part
BSSAP	Base Station Subsystem Application Part
BSSGP	Base Station Subsystem GPRS Protocol
VM	Virtual Machine
VNF	Virtualized Network Function
VNFI	Virtualized Network Function Instance

OS	Operating System
IaaS	Infrastructure as a Service
SIGTRAN	Signalling Transport
GSM	Global System for Mobile Communications
UMTS	Universal Mobile Telecommunications System
LTE	Long Term Evolution
BSC	Base Station Controller
RNC	Radio Network Controller
ISDN	Integrated Services Digital Network
IT	Information Technology
BHCA	Busy Hour Call Attempts
ICT	Information and Communication Technologies
SDN	Software Defined Networking
OS	Operating System

Glossary

CN	Core Network which comprises of the Mobile Switching Server, Media Gateway, Serving GPRS Support Node etc.
OMSIG	Operations and Maintenance Signalling Interface.
TRXSIG	Transceiver Signalling Interface.
Abis Interface	Interface between the BSC and the BTS. Abis signalling links are terminated in the BTS and the BSU in BSC. Abis user plane links are terminated in the BTS and ABDU in the BSC.
A-Interface	Interface between the BSC and the CN for circuit switched services. A-interface signalling links are terminated in CN and BSU in the BSC. A-interface user plane links are terminated in CN and AIDU in the BSC.
Gb Interface	Interface between the BSC and CN for packet switched services.

Hypervisor	Also known as Virtual Machine Monitor, hypervisor is a computer software, hardware or firmware that creates, runs and destroys virtual machines.
Host Operating System	This is the operating system on which the hypervisor runs. In other words, this is the first operating system that is installed on the virtualization platform.
Guest Operating System	This is the operating system of the Virtual Machines that run on top of the Host OS.
eNodeB	Evolved NodeB that performs the functions of a radio controller in a LTE radio access network.
2G	Second generation wireless telephony technology; also called GSM
3G	Third generation wireless telephony technology; also called UMTS
4G	Fourth generation wireless telephony technology; also called LTE
5G	Fifth generation wireless telephony technology; still in specification stages.
C-Plane	Control Plane; refers to the network links carrying signalling information

U-Plane	User Plane or Traffic Plane; refers to the network links carrying the user plane such as speech frames or packet data.
3GPP	Third Generation Partnership Project; It's a collaboration between groups of telecommunications associations that provides system specifications related to GSM, UMTS, LTE and IMS.
Circuit switched traffic	Refers to speech calls in GSM that are established using connection oriented 3GPP BSSAP procedures. An IP BSC and a Cloud BSC do not use circuits for speech calls, but the term is still widely used to refer to voice calls in GSM network.
Packet switched traffic	Refers to packet data calls in GSM network that are established using the 3GPP BSSGP procedures.
Source BSC	This is the BSC which is currently serving the call. During an external handover, this is the BSC which initiates the handover procedure.
Target BSC	This is the BSC where the call will be latched after the handover is completed. During an external handover, this is the BSC which will serve the mobile after the handover procedure has ended successfully.

1 Introduction

Mobile wireless telecommunication networks have evolved immensely over the last 30 years. From the 1st generation to the present day 5th generation wireless network technologies, the evolution goal has been to provide the end user with a global communication reality. In each generation the aim has been to provide a new and improved set of services to the user along with ubiquitous communication. In order to meet his goal, most of the operators in the world have tried to maintain various cellular technologies in tandem. However, they are faced with an ever increasing demand for mobile data without a comparable increase in the available radio spectrum. As a result, many operators are now at a critical point in the lifecycle of cellular network technologies, where they have to shut-down one or more of the older generation cellular technologies such as 2G and 3G and re-use the freed up spectrum for faster technologies such as 4G and 5G. It then seems quite natural to transition only the newer cellular technologies to Telco Cloud as this makes it more attractive and cost-effective to the operator and the telecom equipment vendors. Figure 1 illustrates the evolution of the mobile network technology.

1st Generation (1G)	2nd Generation (2G)	3rd Generation (3G)	4th Generation (4G)	5th Generation (5G)
1981	1992	2001	2010	2020
2Kbps	64Kbps	2Mbps	100 Mbps	10Gbps
Basic voice services using analog protocols	Designed primarily for voice using digital standards (GSM / CDMA)	First mobile broadband using IP protocols (WCDMA / CDMA2000)	Mobile broadband on a unified standard (LTE)	Service aware devices and Internet of Things

Figure-1: Mobile Network Technology Evolution

However logical it seems to shutdown older generation of mobile technologies, this is not an easy decision to make. International Telecommunication Union estimates that 95% of the world's population lives in an area covered by mobile cellular network and about 53% of this population is not using internet (ICT Facts and Figures 2016, 2016). This leads to believe that more than half of the world's population is still surviving on 2nd generation cellular network technology and most of this is in the developing parts of the world. As smartphones penetrate the developing world and operators aggressively push data connection subsidies, the equation is bound to change with more and more subscribers transitioning towards a data centric cellular networking technology. "GSMA Intelligence" estimates that mobile broadband, constituting 3G and above technologies, accounts for 80% of the connections in developed world in contrast to 40% of the mobile broadband connections in the developing world (The Mobile Economy 2016, 2016). It also estimates that by year 2020, the number of 2nd generation mobile connections will drop below three billion excluding the number of Machine-to-Machine connections (The Mobile Economy 2016, 2016).

The story is a bit different in the developed parts of the world where mobile broadband penetration and data demand by users, is driving 2nd generation cellular technology towards a lifecycle termination. At the same time, there are interesting reports that some operators in Europe will shut-down their 3rd generation cellular networks, while the 2nd generation cellular technology continues for years to come. Reasons cited include spectrum management and Machine-to-Machine deployments (The future of legacy mobile networks in Europe, 2016). This leads to believe that 2nd generation cellular technology is still quite relevant in both the developing and developed parts of the world and is bound to remain for years to come. This is also the reason why telecom equipment vendors still have 2nd generation cellular technologies in their Research and Development roadmaps.

While the spectrum used by 2nd generation cellular technology cannot be freed due to the above mentioned reasons, there are other avenues where a technology transition can bring some value additions to the operator. It should be noted that 2nd generation radio equipment were first developed during the 1990s and occupied quite an amount of real estate. Even though there have been hardware developments and size of the components have reduced, a typical 2nd generation equipment still occupies a considerable amount of floor space. For example, a single module of a 2nd generation Radio Controller has a space requirement of 177mm x 444mm x 450mm. The number of modules depends on the traffic capacity and radio network configuration desired by the operator (Multicontroller BSC). Moving these Radio Controllers to the cloud, provide the operator an opportunity to free up real estate. In addition, there is no need to account for specific floor space requirements when capacity upgrades require additional modules, because the entire radio network controller is functioning as a pool of virtual machines in the cloud data center.

1.1 Overview

In wireless telecommunication terminology, Radio Controllers are referred to the network elements that are responsible for controlling the radio transmitting and receiving stations or the base stations. They primarily carry out the functions of radio resource management. In Global System for Mobile communication technology (also known as GSM or 2G), the Radio Controller is called a Base Station Controller (BSC); in Universal Mobile Telecommunication System (also known as UMTS or 3G), the Radio Controller is called a Radio Network Controller (RNC) and in Long Term Evolution (also known as 4G), the Radio Controller is called an eNodeB.

Virtualization brings a disruptive approach to the elements of a telecommunication network. Virtualized Networking Functions (VNF) share computing, input-output and storage resources to optimize the use of a network infrastructure. Since the resources are shared based on usage, there is a framework needed to manage these resources to mitigate variations in usage. This is where Elasticity Management procedures come into picture. Elasticity in a cloud environment enables a business to dynamically mitigate variations in IT resource demands. It ensures that the Telco Cloud gets the required resources – computing, input-output or storage when the demand is high and it also ensures that unused resources are released back into the data center pool when the demand is low.

In traditional networking elements such as the BSC, elasticity is heavily restricted or limited by the hardware components. A telecom network operator, cannot increase the capacity of the Radio Controller to address increased need of radio traffic, on demand. Instead, it needs commissioning and configuring of new hardware. However with the transition of telecommunication networking elements to the cloud, there is now an opportunity to re-design elasticity with very little or no dependency on the underlying hardware. Telecom operator would now have the freedom to scale-in and scale-out resources on demand and it may be possible to perform elasticity autonomously, without user intervention. This study is focused on designing an elasticity framework for the 2nd generation Base Station Controller in the cloud. Figure 2 illustrates the BSC interfaces on the cloud.

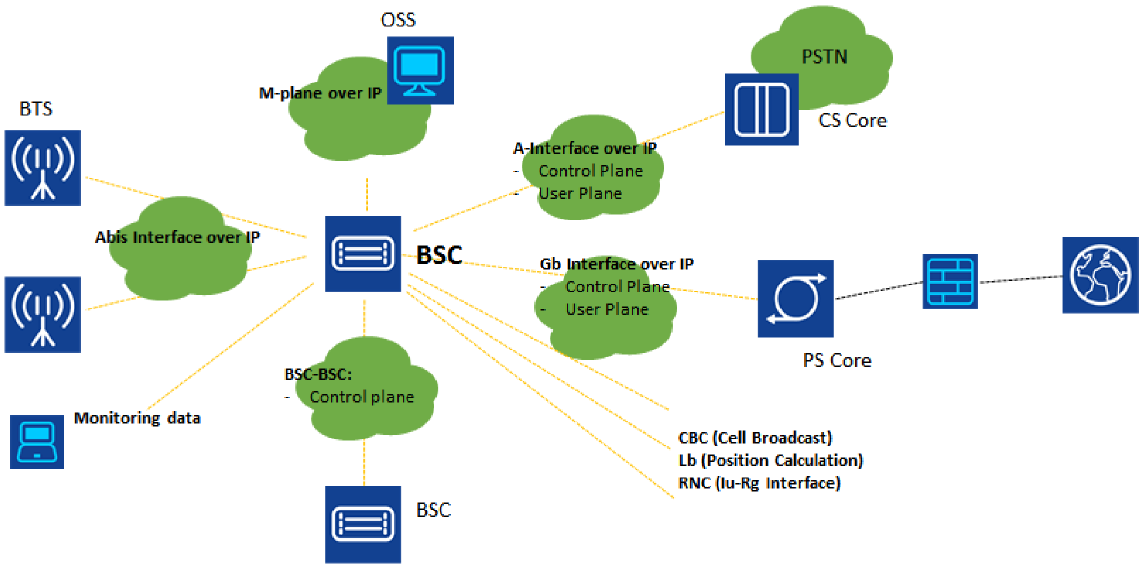

Figure-2: BSC Interfaces on the Cloud

Figure 2 shows the interfaces as hosted in a traditional BSC. The interface between the Base Transceiver Station (BTS) and the BSC is called the Abis interface. The interface between the BSC and the Circuit Switched Core Network is called the A-interface. The term "circuit switched" refers to speech calls that are established using connection oriented procedures defined in Third Generation Partnership Project (3GPP) 48.008 specification, also known as the BSSAP (Base Station Subsystem Application Part, 2016) specification. The interface between the BSC and the Packet switched Core Network is called the Gb interface. The term "packet switched" refers to packet data calls that are established using the procedures defined in 3GPP 48.018 specification or BSSGP (Base Station Subsystem GPRS Protocol, 2016) specification. Such calls are based on the General Packet Radio Service (GPRS) or Enhanced Data Rates for GSM Evolution (EDGE) technology. BSC also supports the Cell Broadcast interface towards the Cell Broadcast Center, Lb interface towards the Serving Mobile Location Center (SMLC) and IuRg interface towards the Radio Network Controller in 3G. BSC also has an interface towards the Operations Support and Sub-system and a Radio Network Subsystem Application Part (RNSAP) based interface towards other BSCs in the network. There is also a proprietary interface for monitoring and collecting logs from the BSC for debugging network related issues.

The architecture and interfaces remain the same when the Radio Controller transitions to the cloud. The traditional traffic processing units are hosted on dedicated hardware units on the BSC. In the cloud, BSC acts like a Virtualized Networking Function (VNF) and the traffic processing units are running as Virtual Machines (VM) in the VNF. These are also called Virtualized Networking Function Instances. In other words, the underlying hardware is not specialized, but general purpose IT hardware resources. A typical example of such hardware resource is an Intel or AMD based server with multi-core processors. A BSC Virtualized Networking Function (VNF) configuration with interfaces towards external network elements is shown in Figure 3. Traffic dispatchers for the Abis and A-interface control plane serve the purpose of terminating the Stream Control Transmission Protocol (SCTP) endpoints for signalling towards the Base Transceiver Station (BTS) and Core Network (CN) respectively. This helps to scale all the signalling units in the BSC. However the traffic dispatchers shown in the picture are not in the scope of this thesis.

The traditional Radio Controller architecture has a tight binding between the application software and the hardware. Hence, the scaling options are very limited or restricted without major changes to the hardware. Figure 3 shows the typical Virtualized Networking Function (VNF) configuration of the interfaces.

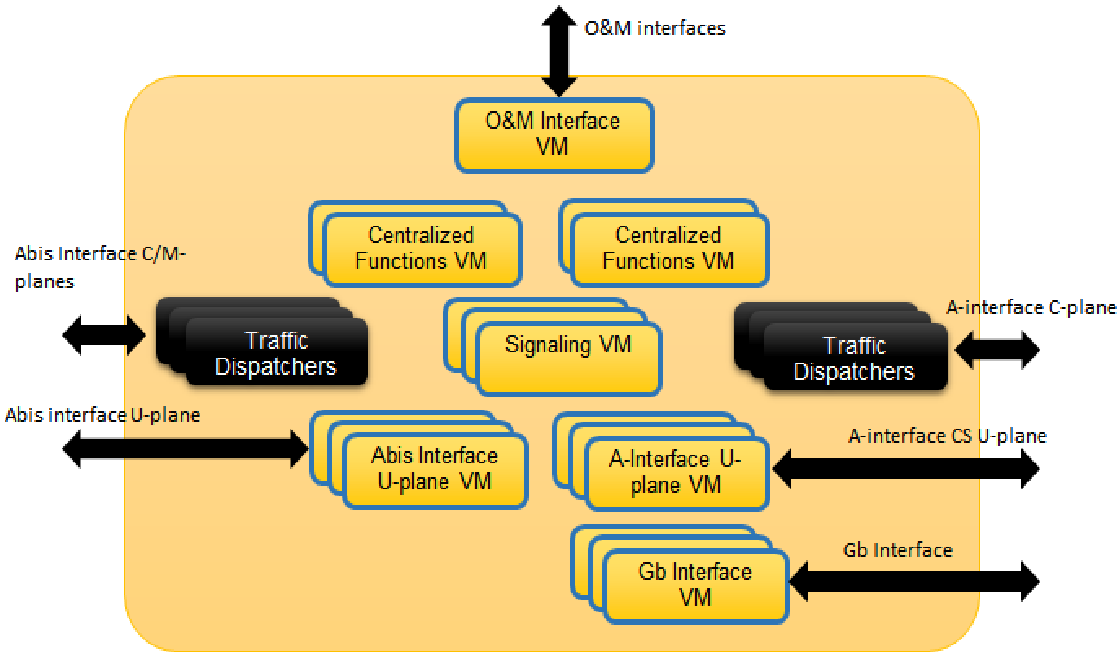

Figure-3: Typical VNF configuration of the Interfaces

With the Radio Controllers functioning as software entities on general-purpose hardware, in the cloud, there is now an opportunity to define frameworks for easy scaling in and scaling out of the Radio Controllers. This study focuses on defining this framework for the BSC.

1.2 Study Purpose and Methodology

The research objective related to this topic is to determine ways to define elasticity framework and procedures on the Cloud BSC such that it provides better services than the traditional hardware bound architecture.

The methodology to develop the framework involves the following steps:

1. Detailed study of the legacy architecture has to be completed, especially those areas related to dynamic resource management and resource expansion in BSC.

2. Detailed study of the new architecture and platform of Telco Cloud has to be done, especially that of BSC. Platform study is essential, as most of the services for elasticity management will be provided by the new Telco Cloud platform.

This will be a continuous study because the new architecture is still evolving and it is necessary to keep abreast of the changes.

3. Finally, application based elasticity management procedures will be defined. This will include both scaling-in and scaling-out options.

A map of the research design is shown in Figure 4. The study starts with an investigation of the existing knowledge related to BSC architecture. This includes resource expansion or resource reduction procedures. The study continues to investigate the new Telco Cloud platform and architecture. Here again the focus is on elasticity management services provided by the Telco Cloud platform and possible application related enhancements to use these services. The study then proceeds to propose new procedures and framework for elasticity management including scaling-in and scaling-out procedures. Finally, the proposals are evaluated and provided recommendations are used as a basis for drawing implementation specifications for the Cloud BSC product.

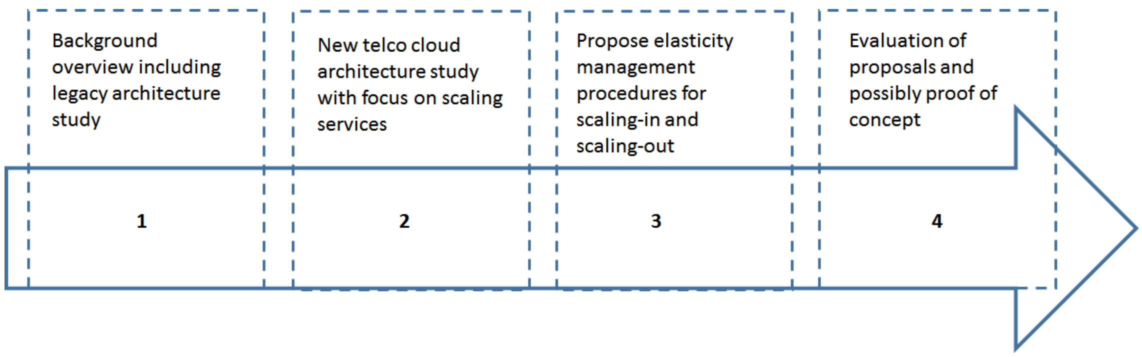

Figure-4: Research Design

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2 Existing Technologies and Solutions

This chapter discusses the existing architecture and framework of a 2nd generation Base Station Controller.

2.1 Internet Protocol – Base Station Controller

A cloud based solution is entirely dependent on Internet Protocol (IP) based transport for its control and user plan data. IP is by far the most common communication protocol used in digital networks, where information is exchanged between a source host and a destination host solely based on IP addresses. Information is transferred as datagrams or packets. When thinking of Telco Cloud, it makes more sense to build further or enhance an existing technology that already uses such IP transport options. This chapter describes an IP based Base Station Controller that is the foundation for the new cloud based Base Station Controller.

2.1.1 General Aspects

This section describes how BSC interfaces with external network elements and how the internal functional units are positioned in the hardware framework. Figure 5 shows a typical interface layout for an IP based BSC.

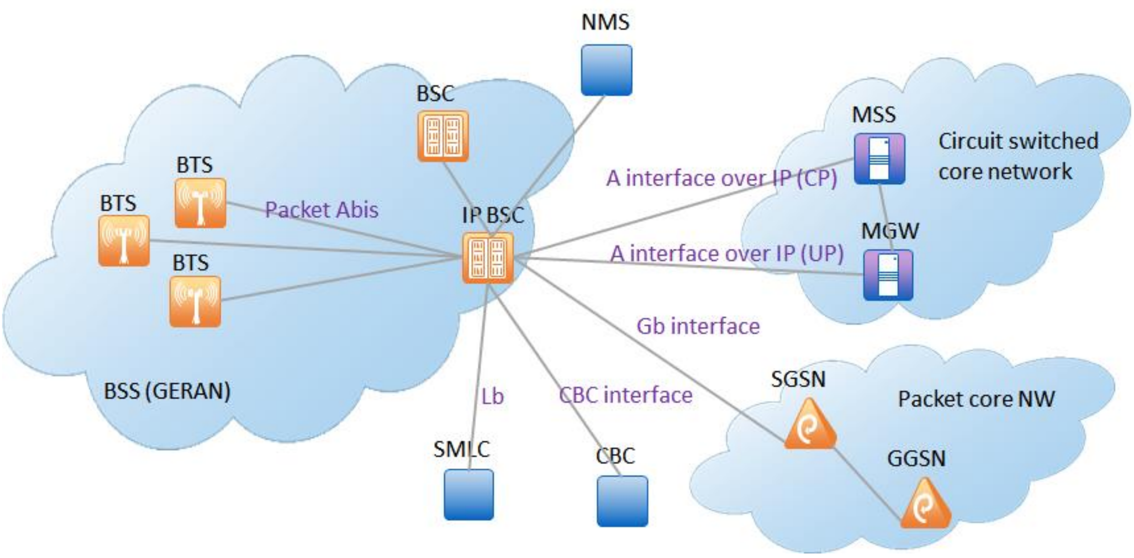

Figure-5: BSC with all IP interfaces

A cloud solution based BSC will use the same interface layout, i.e., all the interfaces use the IP transport option. However, the difference is in the hardware layout. Figure 6 shows a typical hardware layout of an IP BSC.

Abis Interface and A-interface Signalling Unit	Abis Interface and A-interface Signalling Unit	Abis Interface and A-interface Signalling Unit	Abis Interface and A-interface Signalling Unit
Abis Interface and A-interface Signalling Unit	Abis Interface and A-interface Signalling Unit	Abis Interface and A-interface Signalling Unit	Radio Resource Management Unit
Operations and Maintenance Unit	A-interface User Plane Unit	A-interface User Plane Unit	A-interface User Plane Unit
Abis-Interface User Plane Unit	Abis-Interface User Plane Unit	Abis-Interface User Plane Unit	Abis-Interface User Plane Unit
Packet Control Unit – Packet Switched User Plane	Packet Control Unit – Packet Switched User Plane	Packet Control Unit – Packet Switched User Plane	Packet Control Unit – Packet Switched User Plane
Backplane and Switching Units			
Backplane and Switching Units			

Figure-6: HW Layout of an IP BSC

The hardware modules that process control and user plane traffic are tightly coupled in a rack as shown in Figure 6. "Abis Interface and A-interface Signalling Units" are responsible for handling and processing of control plane signalling for speech calls. "A-interface User Plane Units" and "Abis interface User Plane Units" are responsible for handling the user plane traffic or the traffic related to the speech calls. In order to increase the user or control plane processing units, there is a need to commission additional hardware. This is not a flexible exercise if there is not enough real estate for the new hardware. In certain cases, a compromise has to be made such that control plane capacity is reduced to adjust the increase in user plan processing units.

2.1.2 Scaling via Hardware

The previous section outlined how hardware scaling is not a straightforward task in the Base Station Controller. This section introduces an example of such a scaling.

In Figure 6 the Base Station Controller has seven control plane processing units and seven user plane processing units. Based on Key Performance Indices of the network, a service provider may have the need to increase the control plane processing elements because statistics indicate that cellular traffic was adversely impacted due to unavailability of enough signalling processing units.

In order to increase the signalling capacity, one option is to increase the rack space within the backplane cabling limits. This way additional signalling cards can be added in this space. It is also possible that the service provider does not have the option to increase the rack space for housing the expanded capacity. In this case, some of the other interface processing have to be removed in order to house the new units. Such a compromise is not necessarily sustained over a long duration and service provider may have to roll back to the previous configuration. Figure 7 shows an example of compromising with A-interface user plane capacity to increase Abis signalling capacity:

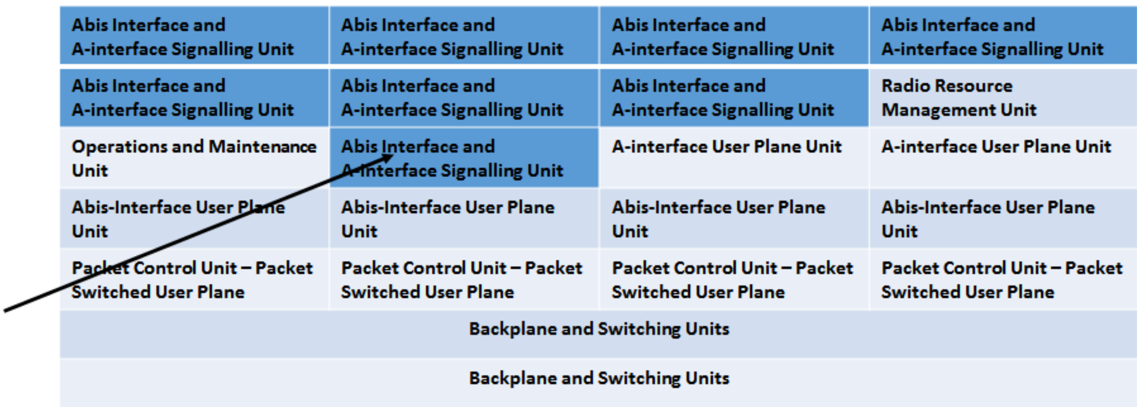

Figure-7: HW Layout of an IP BSC with increased signalling capacity at expense of user plane capacity

The above paragraphs consider the situation of capacity expansion. There could also be requirements to reduce the capacity if there is not enough traffic on the Base Station Controller. This often happens when the service provider has to cater for increased capacity requirements during mass sporting or religious events. During such events the network capacity is increased temporarily, using the HW expansion methods explained in earlier paragraphs. But later when the requirement is no longer valid, it again requires complex commissioning operations to remove the additional hardware. Certainly the other alternative is to leave the configuration as such, even if the capacity is not necessarily used and this is an issue for the telecom operator.

2.1.3 Scaling via Software

In this section software features which assist in autonomous scaling of Base Station Controller resources are discussed.

The most common solution is controlling the availability of a Transceiver (TRX). Such solutions have trigger parameters dependent on the volume of traffic and duration when this trigger is supervised. As an example, when the traffic in an area is low enough for a certain period of time, a Transceiver (TRX) serving this area can be chosen for shut-down to save power. If there are existing calls on this TRX, they are moved to another TRX through a handover procedure. Third Generation Partnership Project (3GPP) specified handover sequences are described in Appendix. Once the TRX is empty, it is shut-down. Similarly when the cellular traffic in the area begins to increase, BSC decides to power up the TRX, which then starts serving the increased traffic.

In the traditional hardware based BSC, there are hardly any software based solutions for scaling. Ideally telecom networks are defined with a pool of resources, but the usage of pool based resources is restricted to load balancing. It is not designed for dynamic assignment of resources, as and when traffic demands increase or decrease. In other words, the traffic is allocated to these resources in a weighted round robin fashion where the least loaded resource is allocated to serve the traffic. This is true for channel allocation in a cell as well as for user plane resource allocation on the network element interfaces. This is not scaling in true sense but the closest one can get to resource management in traditional telecom networks.

2.2 Research Design

This section outlines the research design for this thesis. The transition of the Base Station Controller in the cloud opens up opportunities where the architecture can be re-defined to support intelligent and true scaling of resources. Since the underlying platform is also re-vamped, there is a possibility to use the platform services to facilitate scaling. However this thesis involves studying and proposing changes to the application software in order to facilitate elasticity procedures in the Cloud BSC.

The next stage is to identify the interfaces and VMs that will be subjected to scaling of resources. Complexity and limitation of the existing architecture are also assessed while identifying the interfaces and VMs for scaling on demand.

Once the interfaces and Virtual Machines (VM) are identified, triggers for scaling have to be identified. Triggers are more or less derived from the legacy architecture and recommendations will be drawn on how these triggers will be utilized in the cloud based solution to scale resources on demand.

Finally autonomous and manual scaling options are discussed in order to decide the best possible option for Cloud BSC. Phasing of the Cloud BSC product is also considered when deciding on these options.

2.3 Expected Outcome and Results

The expected outcome are recommendations of scaling-in and scaling-out solutions for the Base Station Controller. These include the interfaces to be scaled, the triggers for scaling and an assessment of autonomous against manual scaling options. Some scenarios will also be discussed to see the relevance of each scaling option.

The evaluation of results is based on applying these proposals to the Cloud Base Station Controller. These proposals are detailed further in “Implementation Specification” of the actual product which is reviewed and approved by field and domain experts.

3 Cloud Based Radio Access Network

This chapter discusses the general aspects of a Telco Cloud solution and where the Base Station Controller lies in this framework.

3.1 Virtualization Aspects

This section discusses the general virtualization aspects. In broad terms virtualization abstracts the physical hardware resources into virtual resources. As such, this does not impact the application architecture too much, because the application still gets the pre-allocated set of virtual resources. The impacts are realized when cloud computing is introduced in the virtualization framework. Cloud computing enables on-demand virtual resources and this has deep implications on the application architecture.

Every application should leverage the cloud capabilities to get full benefits of on-demand resource availability. This essentially means that, every application could be re-designed to be elastic or in other words applications can now scale-in and scale-out on demand using the cloud framework. And just like any software application, this is fully applicable to a telecommunication application.

3.2 Network Element Virtualization

Network Element Virtualization defines Network Elements or Network Functions running on standard Information and Communication Technologies (ICT) hardware and using hardware virtualization technologies. It provides high degree of automation, flexibility and paves the way for Software Defined Networking (SDN). Figure 8 illustrates the Telco Cloud architecture.

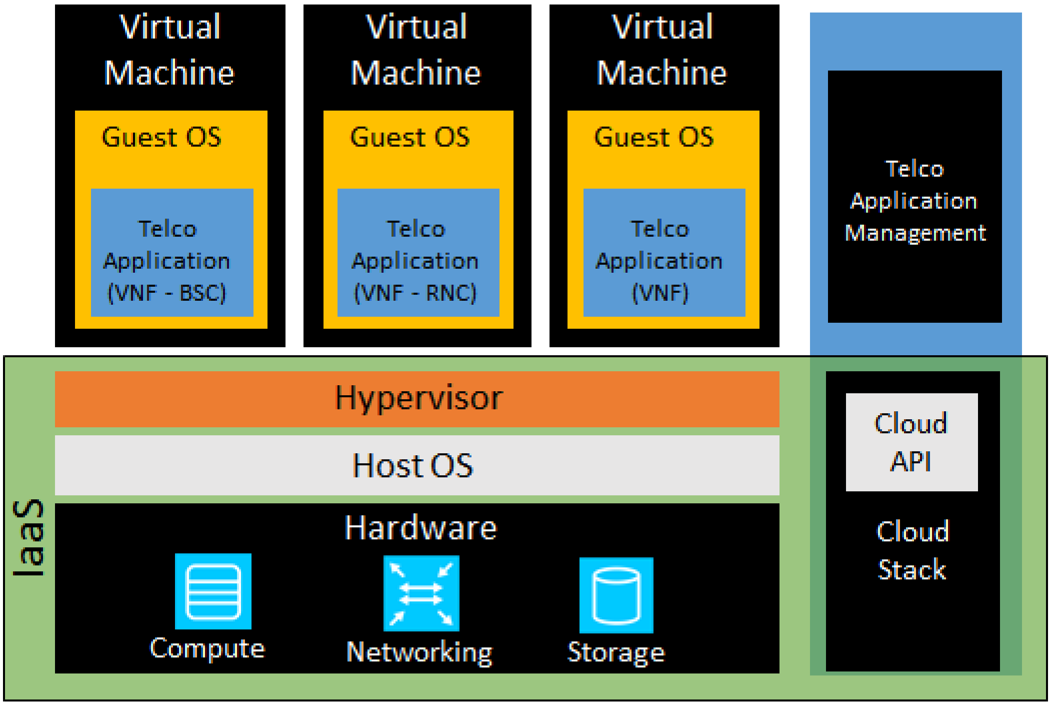

Figure-8: Telco Cloud Architecture

Figure 8 depicts a pool of physical hardware resources that includes computing hardware, storage hardware and networking hardware (Basics of Telco Cloud, 2015). This is controlled by an operating system which is called the Host Operating System. A resource manager runs on top of the operating system that schedules and distributes the physical resources to various applications. This resource manager is called the Hypervisor.

In a telecommunication cloud framework, a network element such as the BSC runs as a network function on top of the Hypervisor (Cloud BSC Architecture Specification, 2016). Typically the BSC software itself has its own operating system and this is called the Guest Operating System. Other network elements also run on top of the Hypervisor. For an operator this means, radio controllers of different radio access technologies such as BSC and Radio Network Controller (RNC) can be consolidated as network functions running on top of standard Information Technology (IT) hardware as shown in Figure 8.

This kind of framework greatly simplifies the network architecture in a sense that operator does not have to deal with the proprietary network element hardware anymore.

3.3 Enabling Cloud BSC Solution

This section discusses the basics of a Cloud BSC solution. Figure 9 is an extension of the picture shown earlier in Figure 3. It indicates the position of various component units in the Cloud BSC. Within the BSC Virtualized Network Function (VNF), the Functional Units are mapped into Virtual Machines (VM) 1:1. These VMs are also known as Virtualized Network Function Instances (VNFI). Figure 9 shows the various VMs and the interface functions that they handle. The role of these units are described in subsequent sections.

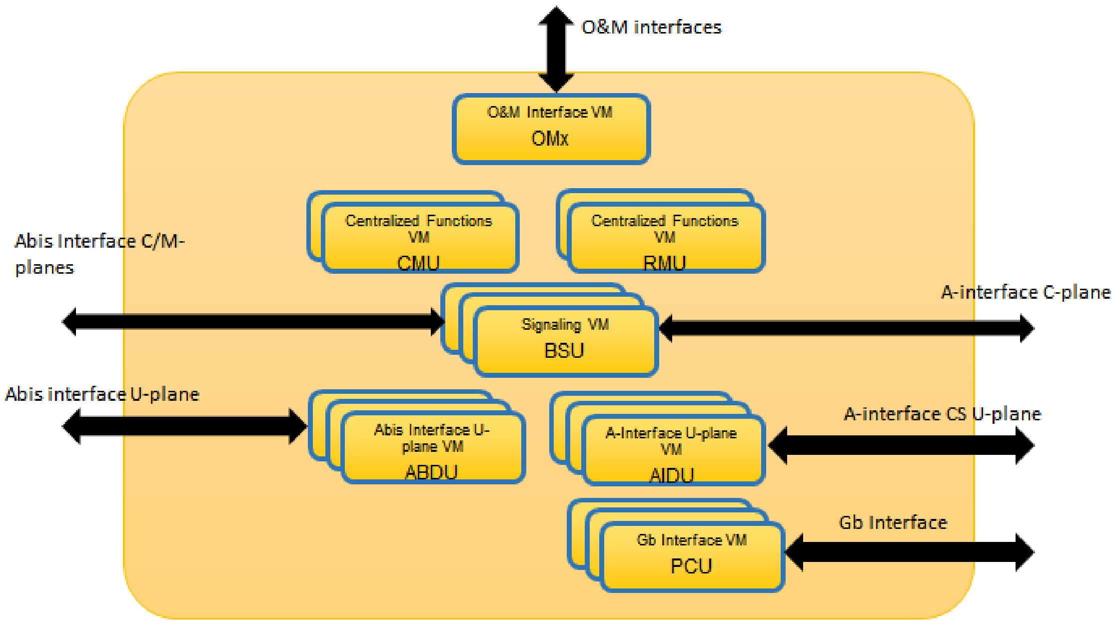

Figure-9: Interface handling VMs in a Cloud BSC

The traffic dispatcher units shown earlier in Figure 3 are not planned for the first phase of Cloud BSC deployment and therefore they are excluded from the scope of discussion in this thesis.

4 Scaling in Cloud BSC

This chapter discusses the scaling procedures in detail. It also discusses the actions needed in the Base Station Controller to manage these procedures with minimum service impact.

4.1 Identifying Interfaces and Virtual Machines for Scaling

This section discusses how the interfaces and Virtual Machines are identified for scaling operations. The key to efficient management of resource lies in identifying the appropriate interfaces and Virtual Machines (VM) that can be subjected to the scaling procedures. Figure 5 identified the various interfaces of a BSC in a cellular network. Each interface can be further divided into two logical planes – control plane (C-plane) and user plane (U-plane). Signalling information between the network elements is exchanged over the control plane. This includes the information required to setup the user plane resources for the connection. Once the user plane is setup, all voice and data traffic is carried over the user plane. In some cases, signalling information is also carried over the user plane which may be faster and more efficient depending on the use case. Such procedures are not in the scope of discussion in this thesis, but examples of such scenarios can be found in Third Generation Partnership Project (3GPP) specifications.

BSC has two main external interfaces:

1. A-interface – The interface between BSC and Core Network.
2. Abis-interface – The interface between BSC and Base Transceiver Station.

Interface handling protocols are implemented in the application software that runs on hardware units in a traditional BSC. Control plane handling is done in BSC Signalling Unit (BSU) and the speech call related user plane handling is done in Abis Interface Data-Plane Unit (ABDU) and A-interface Data-Plane Unit (AIDU). The packet data user plane handling is done in Packet Control Unit (PCU). In addition to the interface handling units, there are centralized units that maintain the radio network database and perform radio resource management procedures. These are the Central Management Unit (CMU) and

Radio Management Unit (RMU) respectively. The BSU, ABDU, AIDU and PCU have a pool redundancy model, while the centralized function handling units – CMU and RMU have a one-one redundancy model. In this thesis, the scope is limited to analysing the scaling procedures for pool redundancy units, i.e., BSU, ABDU, AIDU and PCUs.

The Abis and A-interface control planes are terminated on the signalling units, i.e., the BSU, as in a traditional BSC. The scaling procedures can be applied to the interfaces or the VMs that have replaced the hardware units. In Figure 9, a one-one correspondence cane be seen between the user plan interfaces and the Virtual Machines (VM) handling them. In other words, there are Abis Interface Data-Plane Units (ABDU) for handling Abis user plane traffic and there are A-interface Data-Plane Units (AIDU) for handling A-interface user plane traffic. However, for signalling, both the Abis and the A-interface control planes are handled by the BSU VMs. The control plane scaling procedures used for the Abis interface may not be suitable for the A-interface because the signalling links and control plane traffic volumes vary on these interfaces. A simple example to illustrate the difference is a paging procedure. A BSSAP (Base Station Subsystem Application Part, 2016) Paging Message on the A-interface can result in multiple Abis paging messages sent on the radio network. Hence, it is more practical to define scaling procedures for the various Virtual Machines (VM) rather than the individual interfaces. The following sections discuss the scaling aspects of these VMs in more detail.

4.2 Scaling of BSC Signalling Unit Virtual Machines

This section describes the various aspects of scaling the BSC Signalling Unit (BSU) Virtual Machines (VM). This scaling operation can be further divided into two parts:

a. Scaling of Abis functions.
b. Scaling of A-interface functions.

Abis and A-interface signalling functions use Stream Control Transmission Protocol (SCTP) as the transport layer protocol for routing messages on the interfaces. On the A-interface, SIGTRAN (Signalling Transport, 1999) protocol is used over SCTP, while on the Abis interface, ISDN User Adaptation (IUA) protocol is used over SCTP. The Abis signalling function can be further sub divided into Operations and Maintenance (O&M) signalling functions called O&M signalling or OMSIG and call specific signalling functions handled by Transceivers (TRX), called Transceiver Signalling (TRXSIG). Abis Layer 3 messages for OMSIG and TRXSIG are carried over IUA between the BSC and the Base Transceiver Station (BTS).

The A-interface signalling function utilizes M3UA (MTP Level 3 User Adaptation Layer, 2006) protocol for carrying Layer 3 messages over SCTP. This enables A-interface related SCCP (Signalling Connection Control Part, 2001) and BSSAP (Base Station Subsystem Application Part, 2016) messages to be carried over M3UA (MTP Level 3 User Adaptation Layer, 2006) between the BSC and the MSS.

Communication between the BSC and Core Network or the BSC and BTS is established via SCTP Associations. In addition to the other parameters, source and destination IP addresses are included in the association. Since the BSU VMs in the BSC handle the Abis and A-interface signalling, the BSC side IP addresses in the SCTP association sets correspond to that of the BSU VMs. Abis and A-interface signalling traffic are differentiated using separate Virtual Local Area Networks (VLAN).

A-interface signalling plane is further divided into two parts. The Internet Protocol (IP) termination part, where the actual M3UA (MTP Level 3 User Adaptation Layer, 2006) links terminate and the application part where the upper layer messages, are handled. The application part handles the SCCP (Signalling Connection Control Part, 2001) and BSSAP (Base Station Subsystem Application Part, 2016) protocol defined messages while the platform services handle Message Transfer Part (MTP) level routing protocol messages. MTP is part of the common channel signalling network. The architecture is defined such that the M3UA (MTP Level 3 User Adaptation Layer, 2006) packets carrying application level messages are terminated in certain BSU VMs and from there-on the application level messages are extracted and distributed to same or different BSU VMs to be processed further. Ideally in a traditional hardware based BSC, the M3UA (MTP Level 3 User Adaptation Layer, 2006) links are terminated on every BSU to provide better redundancy. However, depending on the other functions configured on the same BSU VMs, it is also possible to restrict the M3UA (MTP Level 3 User Adaptation Layer, 2006) link terminations to certain BSU VMs, to evenly distribute the VM load. This is because, BSU

VMs also perform other functions including Abis interface handling which can possibly generate uneven VM load depending on the radio network configuration. Figure 10 illustrates how M3UA (MTP Level 3 User Adaptation Layer, 2006), SCTP and SCCP (Signalling Connection Control Part, 2001) processing is distributed across the BSU. Figure 10 shows the SCTP and SCCP traffic distribution in BSU VMs.

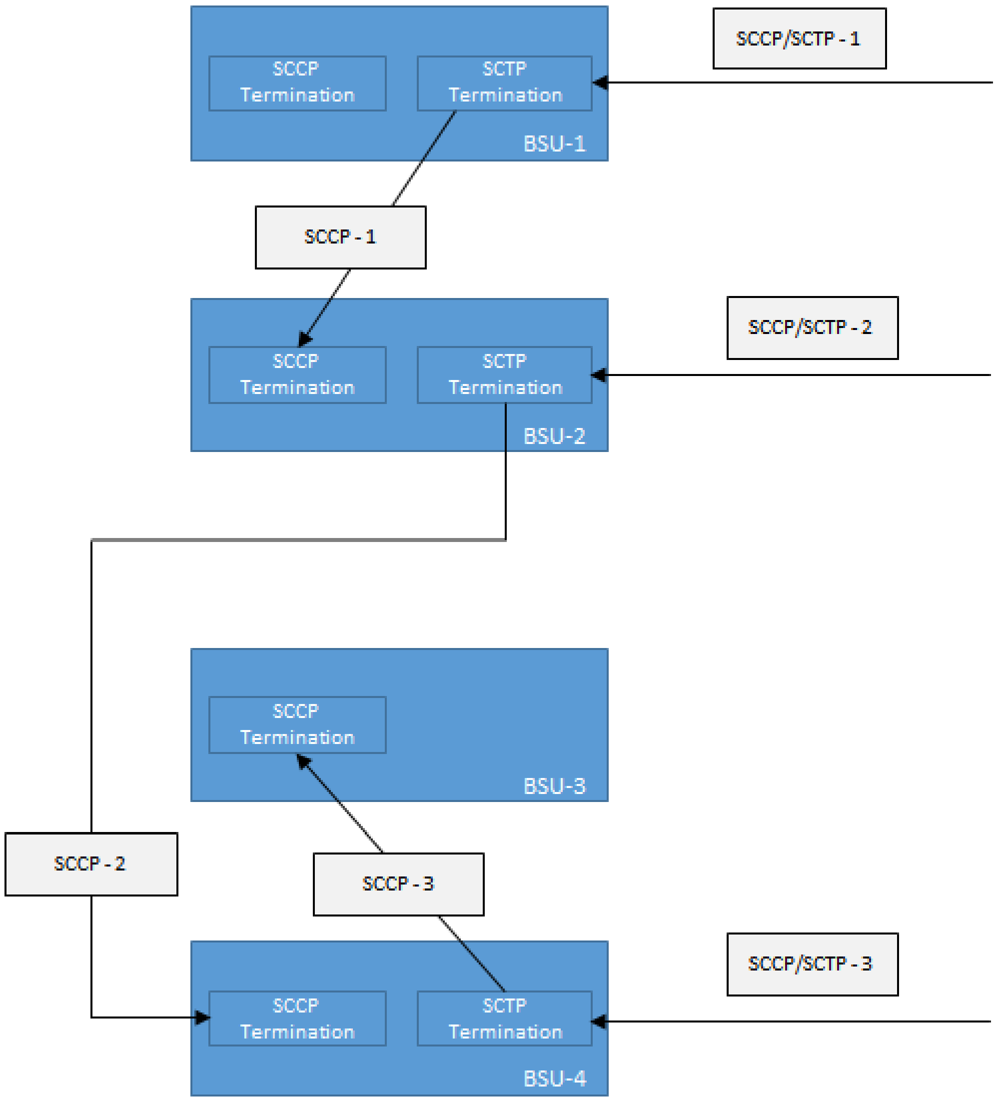

Figure-10: SCTP and SCCP traffic distribution in BSU VMs

As seen above, the application message handling functions including SCCP (Signalling Connection Control Part, 2001) and BSSAP (Base Station Subsystem Application Part, 2016) protocols, are not restricted to certain BSU VMs. In other words, application message handling is performed in each and every BSU VM by specific A-interface message handling processes. Each unique SCCP (Signalling Connection Control Part, 2001) connection with the Core Network is handled by a unique A-interface process.

Similarly the Abis interface signalling plane has two parts. The IP termination part, where the actual IUA links terminate and the application part where the upper layer messages, are handled. The application part handles the Abis Layer 3 protocol defined messages. The difference between A-interface and Abis interface IP terminations is that application message is handled, on the same BSU VM where the IUA links terminate. The application handling itself is divided into two parts – TRXSIG and OMSIG as explained in earlier section. IUA identifiers within the IUA messages indicate which application should handle the received message. The Abis interface transmission architecture is defined such that all call specific signalling for a Transceiver (TRX) is carried by a single Virtual Local Area Network (VLAN). Multiple such TRXs are configured to a single BTS and hence there could be multiple TRXSIGs from a single BTS towards the BSC. However for a single BTS there is only one OMSIG which carries the O&M related Layer 3 messages. OMSIG has its own separate VLAN. For simplicity, if one BTS represents a radio cell, it is highly possible that certain BTSs are serving more traffic than other BTSs. For instance, a BTS configured to serve the downtown part of the city, will easily have more traffic load than a BTS serving a remote sub-urban part of the city. It becomes quite clear now that signalling traffic on the TRXSIG can vary depending on the radio coverage area of the TRXs. This also means that a particular BSU VM handling traffic of the downtown TRXs will need more computing resources than a BSU VM handling the traffic of sub-urban TRXs. Due to the tight binding between the application handlers and IP termination points, scaling of the Abis interfaces should be handled more carefully to avoid disruption of traffic and quality of service. Figure 11 shows how the TRXSIG and OMSIG are distributed across the BSU VMs.

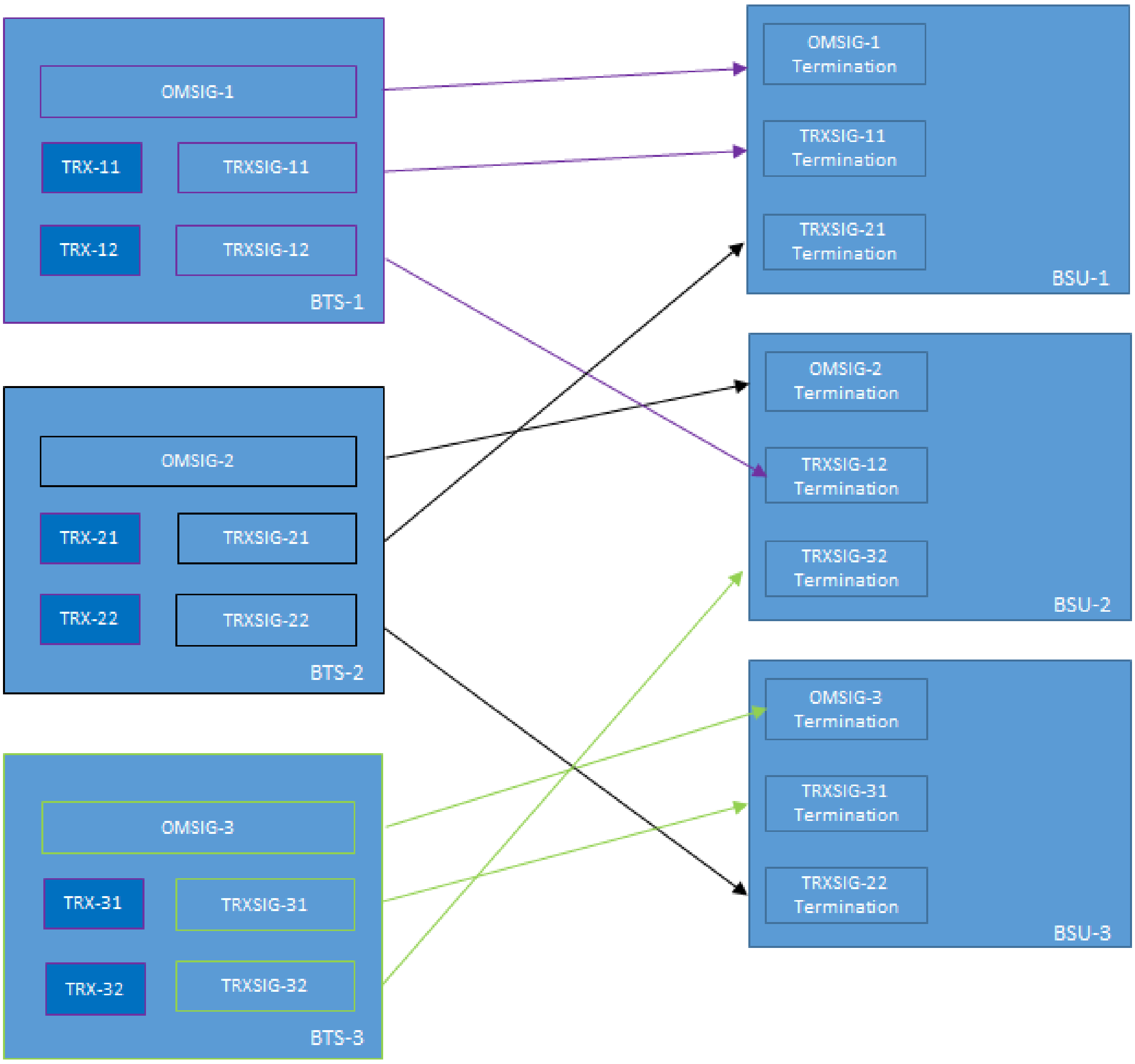

Figure-11: TRX Signalling and O&M Signalling distribution in BSU VMs

All the radio timeslots on a TRX share the same TRXSIG termination on the BSU. However the call specific signalling associated with each radio timeslot is handled by separate Abis message handling processes. In this way each call is associated with a unique Abis handling process.

Signalling traffic related to active calls include both the Abis and A-interface processes as seen in Figure 12.

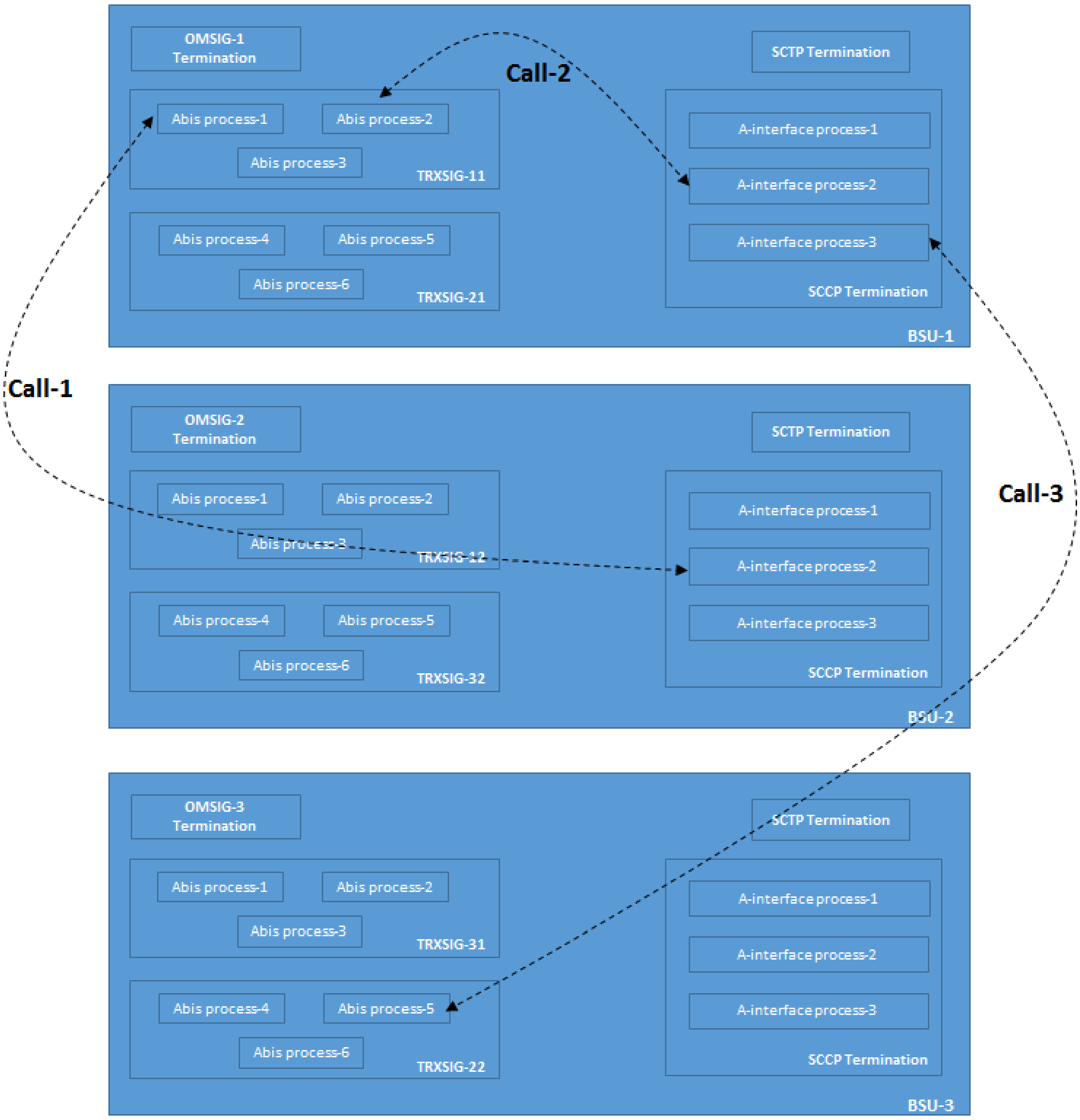

Figure-12: Call specific signalling handling in BSU VMs

Call-1 has originated or terminated on the radio network handled by TRXSIG-11 in Figure 12 and hence the Abis process handling this call is Abis process-1 of BSU-1 VM. The A-interface process – 2, handling the same call is located on BSU-2 VM. Similarly, for Call-2, the Abis process is on BSU-1 VM and A-interface process is on BSU-1 VM. For Call-3, the Abis process is on BSU-3 VM and A-interface process is on BSU-1 VM. This kind of A-interface and Abis-interface handler distribution ensures that signalling load is evenly distributed across BSU VMs.

In addition to the speech traffic discussed above, there is also packet data traffic using General Packet Radio Service (GPRS) and Enhanced Data for Global Evolution (EDGE) technology that are handled in the BSC. The packet data control and user plane are handled by the Packet Control Unit (PCU) VM of the BSC. However the radio management is still done by the centralized radio resource manager process on the Radio Management Unit (RMU) VM. This process distributes the radio timeslots on a Transceiver (TRX) for speech and packet data traffic. The part of the radio network that serves the packet data traffic is called packet switched territory. In other words, a packet switched territory identifies the number of radio timeslots on a TRX that is dedicated to carry packet data traffic. In addition to user provided configuration, there are intelligent features on the BSC that can increase or decrease the packet switched territory based on network demand. Figure 13 shows some examples of packet switched territory on the TRX.

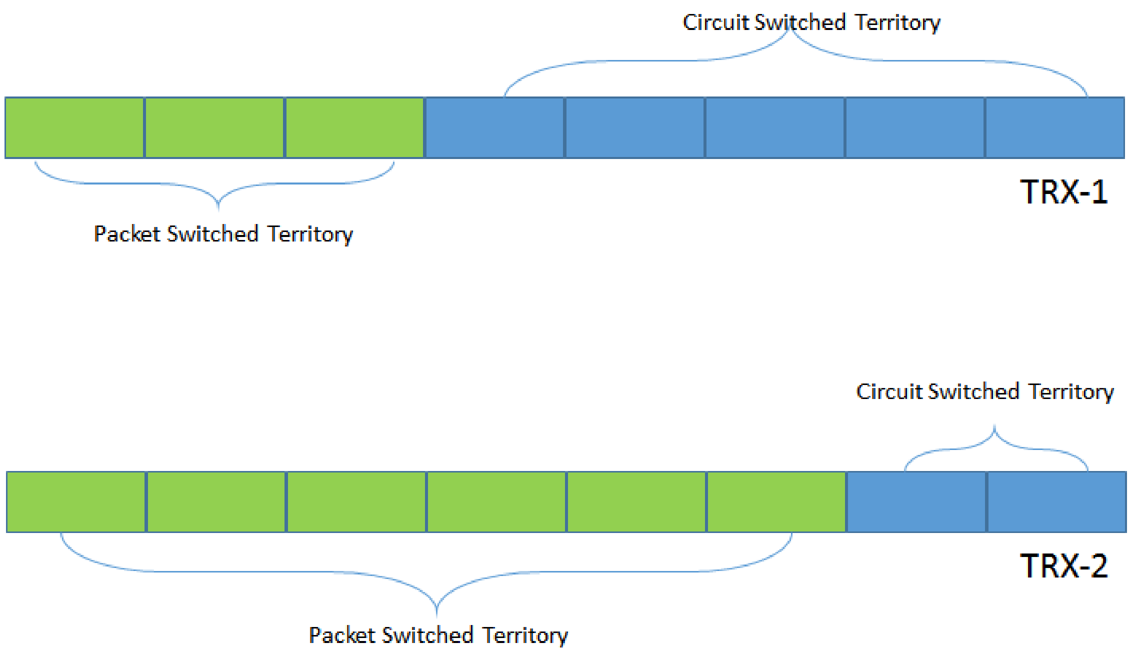

Figure-13: Circuit and Packet Switched Radio Territory

Packet switched territory on a Transceiver (TRX) can be increased using territory upgrade procedures, where the signalling is negotiated between the Packet Control Unit (PCU) VMs and the radio resource manager process on Radio Management Unit (RMU) VM. Similarly territory downgrade procedures are used to reduce the packet switched radio timeslots on a TRX based on demand.

The next section describes the requirements for scaling of BSU VMs taking into consideration the configured interfaces, signalling traffic distribution and territory management of radio on the BSU VMs.

4.2.1 Requirements

Scaling requirements for the BSU VMs consist of:

1. Moving Abis and A-interface terminations related to SCTP Associations, from the BSU.
2. Moving of call specific process handlers from the BSU.
3. Radio network re-allocation among all BSU VMs.

Scaling can be done to add more resources to the network element and this is called scaling-out. Similarly when resources are removed from the network element, the procedure is called scaling-in.

4.2.2 Scale-out of BSC Signalling Unit Virtual Machines

This section discusses the scale-out practicalities of a BSC Signalling Unit (BSU) Virtual Machine (VM). If a new BSU VM is added to the existing BSC configuration as part of the scale-out operation, the new VM's processing power can be utilized to reduce the working A-interface signalling load of the existing BSU VMs. A new Stream Control Transmission Protocol (SCTP) association is created using the BSU VMs IP as the source address and the Core Network's IP as the destination address. This association is added to an existing SCTP association set or a new SCTP association set can also be created. The association set is then added to the existing signalling link and routes. In addition to the terminations in BSC, appropriate association and association sets have to be created on the Core Network as well to utilize the new A-interface route. Once the new A-interface route is configured to both the BSC and Core Network, incoming and outgoing A-interface messages are automatically distributed to the new VM using the existing load balancing algorithms. Such SCTP parameter modifications are complex because it requires re-configuration on the Core Network as well. Besides it is not always necessary to configure a new SCTP association for the A-interface because of the existing redundancy in the links.

In addition to the A-interface IP terminations, there are also A-interface Layer 3 message handling processes on the new BSU VM which are utilized for call specific signalling. There are thousands of such processes on a typical BSU VM and these can be used to serve additional A-interface traffic.

Utilizing the new BSU VM for Abis configuration is not as straightforward as adding new A-interface terminations. In case of the A-interface terminations only limitation is the number of SCTP associations that can be created on a BSU VM and typical limits run in thousands. However, Abis configuration is tightly bound to the radio network configuration. The radio network configuration is mostly governed by the available spectrum although there are spectral efficiency related features on the BSC that can increase the radio capacity by two or even four times. Either way, there are two possible ways to utilize the BSU VM resources for Abis configuration – to configure new radio cells and to reallocate radio cells from existing BSU VMs to the new VM in order to reduce congestion on the Abis interface of existing VMs. The former is an easier process because the new radio network has no ongoing traffic that will be impacted. Once the new cell is configured, it can be opened up for service and this allows cellular traffic to latch on to the new cell and utilize its resources.

The latter option to re-allocate existing radio network configuration, is more complex and often requires a defined radio network re-allocation procedure to effectively utilize the resources of the new VM. This option is quite useful when the operator of the radio network has to account for infrequent mass events in the service area of the BSC. With the traditional hardware based BSC, operator always had to be prepared for such mass events and keep additional hardware in place even though the additional capacity is not used for normal traffic. Let’s discuss this further with an example. An operator in Middle East would have a BSC with below configuration:

- 700 TRXs per BSU VM
- 6 x BSU VMs

Such a BSC can handle a maximum of 734,000 Busy Hour Call Attempts (BHCA) with a mean channel holding time of 120 seconds (BSC EDGE Dimensioning, 2016). During most of the year, average traffic handled by the BSC is only 70% of the maximum BHCA, but during the annual "Hajj" event there is a substantial increase in the traffic. "Hajj" is an annual Islamic pilgrimage to Mecca in Saudi Arabia. In the year 2015, two million Muslims from across the world gathered in Mecca for this event (BBC, 2015). During such a mass event, the BSC has to handle the maximum 734,000 BHCA. During rest of the year, the operator could choose to function the network with less BSU VMs and then configure the additional VMs only before the "Hajj" event. However most of the time they operate with the additional VMs already configured and under- utilize the BSC resources during most part of the year because of the hassles involved in new hardware configuration. With a Cloud BSC, operator could configure five BSU VMs to handle the nominal annual traffic and Abis scale-out operation could be used when the traffic load increases during the "Hajj" event. As part of the scale-out, new BSU VM can be taken into use and the existing Transceivers (TRX) from five BSU VMs could be re-allocated to six BSU VMs to balance the load of the TRXs. Radio network re-allocation has to be a graceful process so that ongoing traffic on the network element is not impacted. This thesis discusses radio network re-allocation procedures in more detail in subsequent sections.

In case of a BSU scale-out there is no ongoing traffic on the new VM. However, traffic starts filling in once the radio network is configured and enabled for the cellular service subscribers to access. This is done by performing radio network re-allocation procedures that is described later in this thesis.

Application level load balancing algorithms in the central Radio Management Unit (RMU) VM ensure that signaling traffic is load balanced across the available BSU VMs. Thus more of the new traffic is routed towards the TRXs and A-interface processes of the new BSU VM. Once the radio network has been configured, the TRXs on the new BSU VM can also be used for packet data traffic by upgrading the packet switched territory on the TRX.

4.2.3 Scale-in of BSC Signalling Unit Virtual Machines

This section discusses the scale-in practicalities of a BSC Signalling Unit (BSU) Virtual Machine (VM). Cloud BSC provides an opportunity to add and remove resources on demand and only when required. The resources here refer to the VMs which can be instantiated to perform the functions of a BSC Signalling Unit (BSU) Virtual Machine (VM) or any other VM in the BSC. Similarly when the traffic demand is low, the VMs can be scaled-in. Just as in scale-out, scaling-in requires the interface and radio network configuration to be moved to another BSU VM gracefully. In addition to this, there are active calls on the BSU VMs, which are being handled by the Abis and A-interface processes. This should also be moved gracefully through radio handovers to another BSU VM.

A-interface signalling links, i.e., the Stream Control Transmission Protocol (SCTP) terminations are the easiest to remove gracefully, due to the redundant architecture of the A-interface IP terminations. The SCTP association set utilizing the BSU IP address is first deactivated. This way all the A-interface signalling messages are routed via alternate SCTP associations on other BSU VMs. Even though there is no service impact due to link redundancy, similar re-configuration is needed on the Core Network as well. Otherwise Core Network could raise severe alarms related to the deactivated SCTP links. Peer element re-configuration such as those in Base Transceiver Station and Core Network is not in the scope of this thesis.

Abis interface signaling links, i.e., the SCTP terminations on the BSC, cannot be removed as easily as the A-interface, due to tighter binding with the radio network configuration. This is possible only if the radio network of the BSU VM itself is redundant and not required anymore. This is quite a rare case. The most common case is where the traffic is low enough on the BSC, such that fewer number of BSU VMs are enough to handle all the active traffic. This means that the TRXs on the BSU VM, selected for scale-in have to be moved to another BSU VM. The other BSU VM has its own IP address and therefore a new SCTP association has to be created for the TRXSIG to operate from the new BSU VM. This can severely disrupt the ongoing calls on the TRXs due to the change in IP address and hence it is absolutely essential to handover the calls from the TRXs of the scaling-in BSU VM to TRXs of other BSU VMs. Third Generation Partnership Project (3GPP) specified handover sequences are described in Appendix. In other words, the

TRXs should be empty of all calls – speech and packet data; before the TRX Signalling (TRXSIG) can be transitioned to another BSU VM. This procedure of moving the TRXSIG to another BSU VM is termed as radio network re-allocation procedure and is described in detail in subsequent sections of this thesis.

If, for instance, the BSU-1 VM shown in Figure 12, was to be scaled-in, it would mean that the TRXSIG terminations of TRX-11 and TRX-21 have to be moved to another BSU VM. TRX-21 is not carrying any traffic. Hence, it can be shutdown, TRXSIG configuration can be deleted and then it can be re-created with new SCTP association on another BSU VM. However TRX-11 has Abis legs of Call-1 and Call-2 which should be moved to a TRX of another BSU VM before TRX-11 can be shutdown.

In order to initiate the moving of the calls, TRX is first locked by the operator. This locking action triggers a forced handover for the calls utilizing the TRXSIG of locked TRX. In Figure 12 there are three calls running on the locked TRXs. Call-1 can be handed over with a normal Intra-BSC radio handover. In this handover the radio resource management application on the BSC selects a target cell which is served by a TRX on another BSU VM, i.e., it ensures that a radio resource and Abis resource is not selected from a TRX of the scaling-in BSU VM. This way the call is gracefully moved to another BSU VM without disruption. Such handovers are very common in the commercial networks when a subscriber moves from one location to another. 3GPP specified handover sequences are described in Appendix. Once the handover is completed for Call-1, Abis interface moves to TRX-12 of BSU-2 VM, while the A-interface process remains unchanged on BSU-2 VM, as shown in Figure 14.

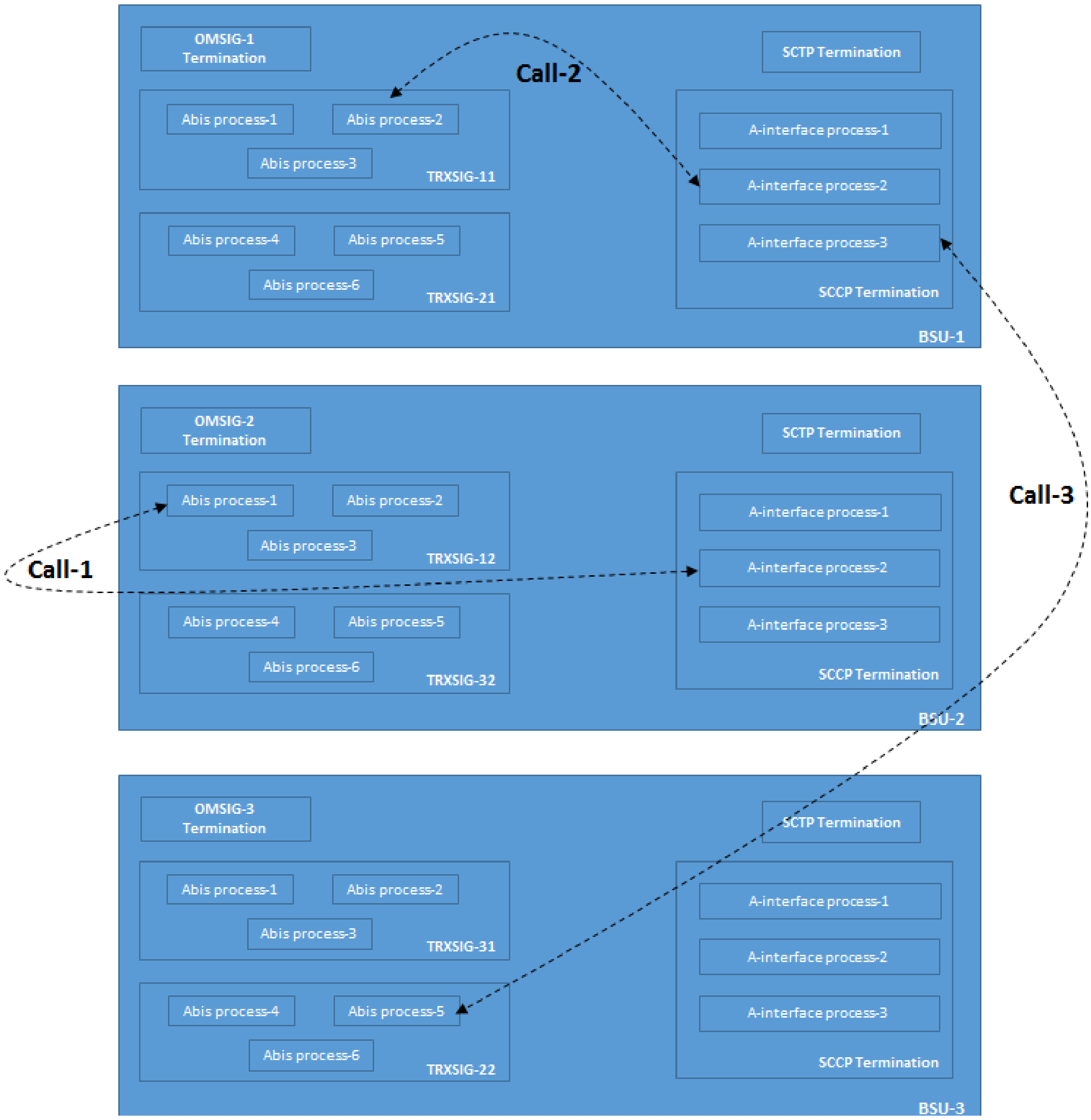

Figure-14: Call specific signalling handling in BSU VMs – Call-1 after handover

Call-2 has both the Abis and the A-interface processes on the same BSU VM. As seen in earlier sections, Intra-BSC handovers are only capable of moving the Abis-interface processes to another BSU VM. Here it is not sufficient to move only the Abis-interface process and hence an Intra-BSC handover does not help the situation. The current architecture is such that it does not support moving the A-interface across the VMs, because in a traditional BSC, the A-interface remains unchanged during the life of the call, while the Abis interface associated with the radio network, keeps changing as long as the subscriber is moving within the coverage area of the BSC. The only situations where the A-interface process changes during the life of the call is when the subscriber moves away from the coverage area of the BSC, triggering an external handover on the source BSC. In an external handover, radio resources are reserved on the target BSC and then the subscriber's control plane is then moved to the target BSC. Subsequently resources on the source BSC are then released and this is treated as end of call for the source BSC. On the target BSC, a new A-interface process then handles the call related signalling for this subscriber and this is treated as a new incoming call for the target BSC.

In order to move Call-2 away from BSU-1, it is possible to use the external handover procedure in such a way that the source and target BSC are the same. In other words, the target for the handover is on the same BSC, but it is treated as a new incoming call that allows the BSC to create a new A-interface process for the call. The radio resource and handover management applications select a radio cell on the same BSC as the target cell for the handover, but the handover is converted to an external handover by sending a BSSMAP HANDOVER REQUIRED message to the Core Network. Since the target cell belongs to the same BSC, Core Network sends BSSMAP HANDOVER REQUEST back to the same BSC. On receiving this message, platform services ensure that A-interface message handler is not selected from a scaling-in BSU VM. Thus the A-interface process is selected on BSU-3 VM based on the load factors. This is a 3GPP defined handover and the specified messages also include the IP addresses of the user plane for the call. In other words, the user plane IP addresses on the A-interface, i.e., between the Core Network and the BSC, is re-negotiated in the external handover messages. During radio resource allocation for this incoming call, radio resource management application also ensures that radio resources are not selected from a scaling-in BSU VM. Thus Abis resources are allocated from BSU-2 for this call. Once the resource allocation is successful, BSC commands the subscriber to move to the target radio channel. 3GPP specified handover sequences are described in Appendix. After the subscriber moves to the target radio cell, BSC releases the source side resources, i.e., Abis process-2 and A-interface process-2 are released and Call-2 continues with the new Abis and A-interface processes as shown in Figure 15.

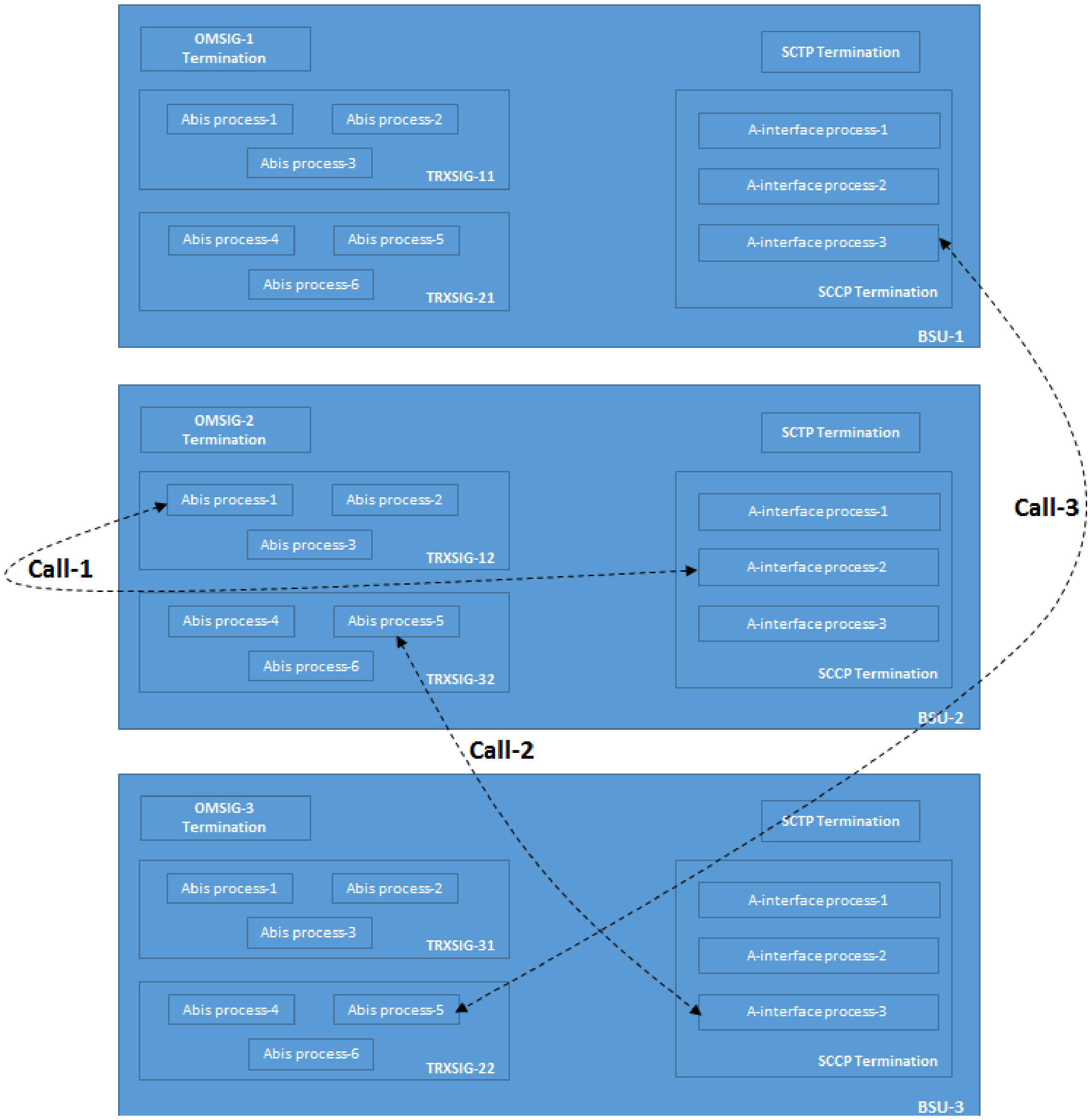

Figure-15: Call specific signalling handling in BSU VMs – Call-2 after handover

Call-3 has the A-interface process on BSU-1 VM while the Abis interface for this call is on BSU-3. Traditional forced handovers on the BSC are always triggered with the Abis process, when the associated TRXs are locked by the user. This is seen for Call-1 and Call-2 where TRX-11 is locked, forcing the handovers to start. For Call-1 the Abis process triggers the handover and call is moved to use an Abis process on another BSU VM via an Intra-BSC handover. For Call-2 even though the handover is triggered by the Abis process movement, application software identifies that A-interface process also has to be moved and it converts the Intra-BSC handover to an external handover where source and targets of the handover are the same BSC. Similar procedures cannot be applied for Call-3 because there is no TRXSIG and no Abis process to trigger the handover on BSU-1. Hence, a new handover trigger and supervision method has to be defined such that the A-interface for the call and the associated A-interface user plane IP addresses are re-negotiated between the BSC and Core Network using the external handover procedure used for Call-2. The essential idea is that once the handover is triggered, the sequence follows the existing external handover messaging flow. This handover procedure is supervised by the central resource management application in the Radio Management Unit (RMU) VM. When this handover is completed, in addition to the new A-interface process, the Abis process and radio cell will also change, because an incoming external handover will always result in new radio resources being allocated for the call. The Abis re-allocation is unavoidable in this case in order to utilize the existing handover messaging sequence. 3GPP specified handover procedures are described in Appendix. Once the handover is completed, Call-3 uses the new processes as shown in Figure 16.

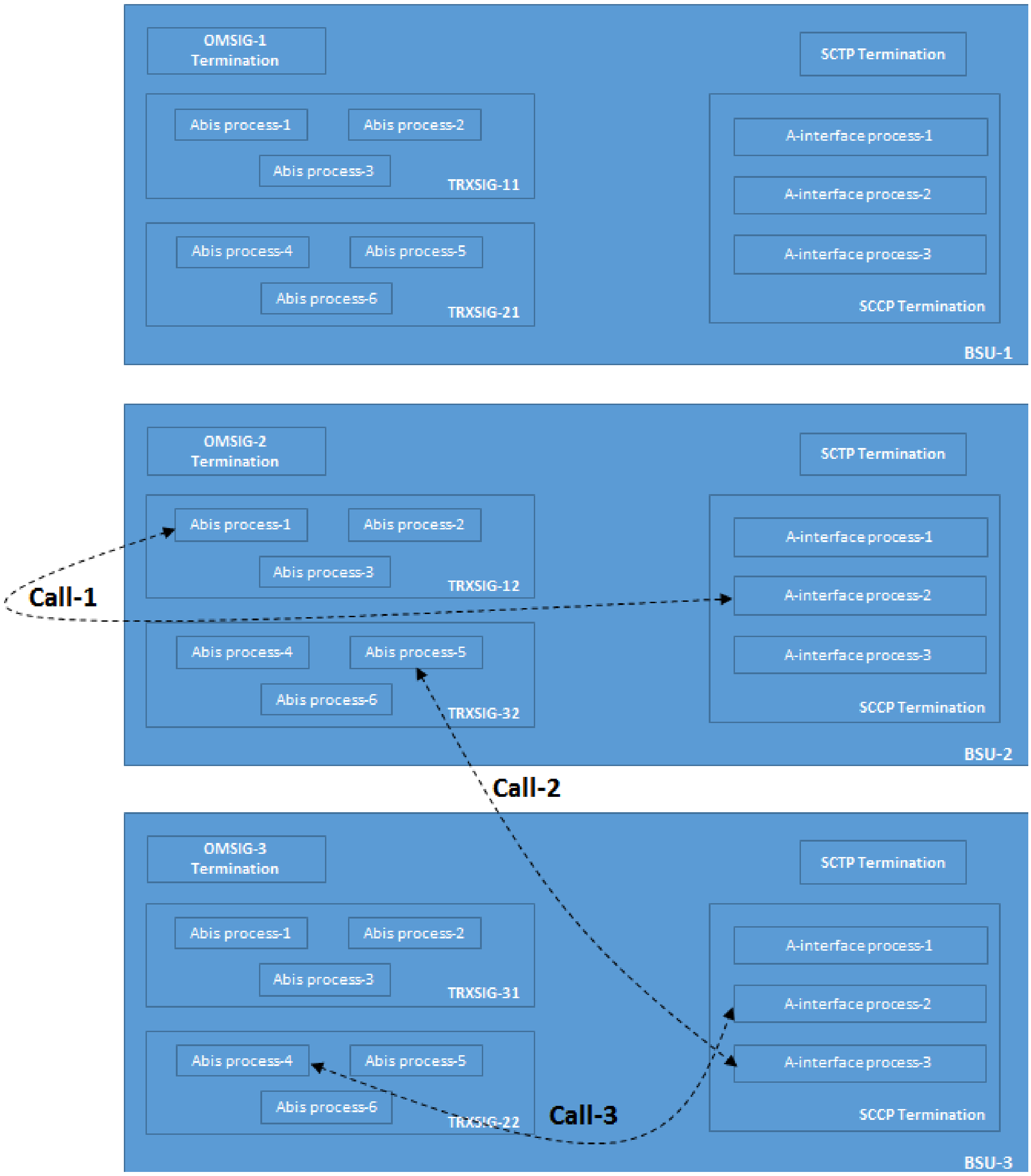

Figure-16: Call specific signalling handling in BSU VMs – Call-2 after handover

Along with speech traffic signalling, there could be packet switched territory configured on the same TRX. There are no handovers performed for the packet switched calls. Instead territory downgrade procedures are initiated by the radio resource manager process and the Packet Control Unit (PCU) VM ensures that packet data calls are released before the packet switched territory is removed from the TRX.

Once the TRX is empty, radio network configuration associated with TRXSIG, can be deleted along with the SCTP association of this TRX. The same TRXSIG is then re-created on another BSU VM and subsequently the SCTP association is re-established. Once this is done, traffic can be filled back to this TRX utilizing the TRXSIG. This includes territory upgrade procedures to increase the packet switched territory on the TRX. This is part of the radio network re-allocation procedure that is described later in this thesis.

This way the BSU VM can be emptied of interface terminations related to SCTP associations of Abis and A-interface along with the radio network configuration and call handling processes. Once the VM is empty, it can be moved to a non-working state and the VM can be shutdown, i.e., the BSU VM has been successfully scaled-in.

4.2.4 Limitations

This section discusses the limitation in scaling the BSC Signalling Unit (BSU) Virtual Machines (VM). The re-allocation of the TRXSIG and A-interface signalling terminations, from one BSU VM to another during scale-in, have been discussed. This also results in the handing over of speech calls and downgrade of the packet switched territory on the impacted TRXs. A-interface signalling as such, is not impacted because of the existing link redundancy model. On the Abis interface, TRXSIG is re-created and SCTP is established on another BSU VM. When this is done, the SCTP association details for the TRXSIG are informed to the BTS, over the OMSIG interface. In other words, TRXSIG re-allocation is possible as long as the OMSIG interface is up and working for the BTS.

However, re-allocation of the OMSIG is not very straightforward and this is also the limitation during the scaling-in of a BSU VM. The OMSIG IP addresses are bound statically between the BTS and the BSC. Changing the IP address on the BSC requires a similar change on the BTS which has to be done manually, since there is no other interface on which the OMSIG IP address negotiation can be done. Besides, a modification of the OMSIG IP address will result in a restart of the BTS. In other words, a BSU VM with OMSIG cannot be scaled-in with the current architecture due to the fact that OMSIG address has to be fixed in the BTS so that initial connection can be established successfully between the BSC and the BTS. However the scaling of OMSIG BSU VMs can be done in later phases of Cloud BSC when the Abis interface traffic dispatchers are taken into use. Traffic dispatchers were mentioned briefly in the beginning of this thesis, and they facilitate hiding of the SCTP terminations for OMSIG, so that BSU VMs can be scaled-in and scaled-out more freely.

4.2.5 Recommendations

This section introduces the recommendations for optimal scaling of BSC Signalling Unit (BSU) Virtual Machines (VM) considering the limitations discussed in the previous section. The foremost recommendation is to tweak the configuration of interfaces in such a way that OMSIGs of all the radio network are configured to a subset of the BSU VMs and not to all the BSU VMs. This subset is then excluded from scaling operations.

There is also a high probability that traffic handling capacity of the Cloud BSC is much higher than that of a traditional BSC. This in turn would need additional BSU VMs to be configured on the Cloud BSC. It is recommended that in initial phase these additional VMs could be specified as the target set for scaling. In other words, OMSIGs of the entire BSC’s radio network is configured to the existing number of the BSU VMs. For example, if the BSC traditionally operated with 6 BSUs and Cloud BSC enables configuring 10 BSUs, the OMSIGs of the Cloud BSC’s radio network is still configured to 6 BSUs. In this way 4 additional BSUs are available for scaling procedures.

It is recommended that scaling is not autonomous in the first phase. Instead the customer or operator is able to check the configuration and traffic amounts on the BSU VM before the scaling operations are triggered manually. Based on the scaling performance, autonomous scaling triggers could be defined in a subsequent versions of the Cloud BSC.

The final recommendation is to perform scale-in, in a graceful and phased manner such that existing load of the system does not increase due to scale-in handover signalling and traffic is not disrupted. For the first release of the Cloud BSC, it is recommended to perform scale-in, in two phases. In the first phase, BSU VM for scale-in is selected and “marked” by the operator. Based on this marking, radio resource manager on the BSC ensures that new speech calls and new packet switched territory upgrade procedures are not performed for the radio network configured on this BSU VM. The VM is left in this state for a pre-defined amount of time, thereby ensuring that traffic load of the VM is reduced gradually. This happens quite naturally when the existing speech calls are released and packet switched territory is downgraded due to lower demand. At the same time new radio for speech calls and packet switched territory is not allocated on this VM. At the end of the allotted time period, the operator could check the traffic load of the VM and trigger the second phase of scale-in, i.e., forced handover of the remaining speech calls and downgrade of the packet switched territory. If a sufficient amount of time is allowed in phase-1, there may not be a need to trigger the phase-2 of the scale-in operation.

4.3 Scaling of Abis Interface Data-Plane Unit Virtual Machines

This section describes the various aspects of scaling the Abis Interface Data-Plane Unit (ABDU) Virtual Machines (VM). ABDU VMs are responsible for transporting the speech call related user plane traffic between the Base Transceiver Station and the A-interface Data-Plane Unit (AIDU) VMs. It handles both the uplink traffic from BTS towards AIDU VMs and the downlink traffic from AIDU VMs towards the BTS. A group of BTSs is served by a single ABDU VM. Every radio timeslot on a TRX has a one-to-one mapping to a UDP port on the ABDU VM that is reserved during a speech call.

4.3.1 Requirements

Just like the BSU VMs described in earlier sections, ABDU VMs can be subjected to scale-out and scale-in operations.

4.3.2 Scale-out of Abis Interface Data-Plane Unit Virtual Machines

This section discusses the scale-out practicalities of an Abis Interface Data-Plane Unit (ABDU) Virtual Machine (VM). A new ABDU VM's processing power can be utilized in an existing BSC configuration in two ways.

1. Configuring the ABDU with new radio network configuration, i.e., new Base Transceiver Station (BTS) and Transceiver (TRX).

2. Configuring the ABDU to serve existing and active radio network, by moving some of the BTSs from an existing ABDU to the new ABDU.

The first type of operation has no impact to the ongoing traffic on the BSC, since the new radio network has not started serving active calls. This is also the simplest scale-out case, where new radio network is configured with the new ABDU VM and then this radio network is unblocked. It now starts handling active traffic. If the traffic involves speech calls, the user plane goes through the newly configured ABDU VM.

The second type of operation is not very straightforward since it requires some kind of blocking for the existing radio network, which in turn results in forced handover of the speech calls and downgrading of the packet switched territory. It should be noted that the ABDU does not handle packet data calls. Such calls are handled by the Packet Control Unit (PCU) VMs. But the BTSs and TRXs handle both speech calls and packet switched data calls. Hence, blocking of the BTSs inadvertently causes the downgrading of the packet switched territory as well. This is also a limitation in the current architecture. Once the BTSs have been emptied, they can be blocked and their configuration can be updated to utilize the new ABDU VM. After the configuration update is successful, BTSs are unblocked and they start serving the traffic. This is part of the radio network re-allocation procedures which is defined later in this thesis. Packet switched territory up-grade procedures and speech calls are established to restore the traffic carrying capacity of the BSC. Handover procedures for the speech calls are defined in next sections since it is a common procedure for both scaling-out and scaling-in of ABDU VMs.

4.3.3 Scale-in of Abis Interface Data-Plane Unit Virtual Machines

This section discusses the scale-in practicalities of an Abis Interface Data-Plane Unit (ABDU) Virtual Machine (VM). If the traffic volumes on the BSC are low enough to be sustained by lower number of ABDU VMs, existing ABDU VMs can be scaled-in. Scaling-in of ABDU VMs requires blocking of the radio network configured on this ABDU. If there is active traffic on the scaling-in ABDU VMs, those calls need to be handed over to an-other ABDU or in other words handover should be done, to move the calls to a radio network served by another ABDU. Figure 17 shows the operation to be performed.

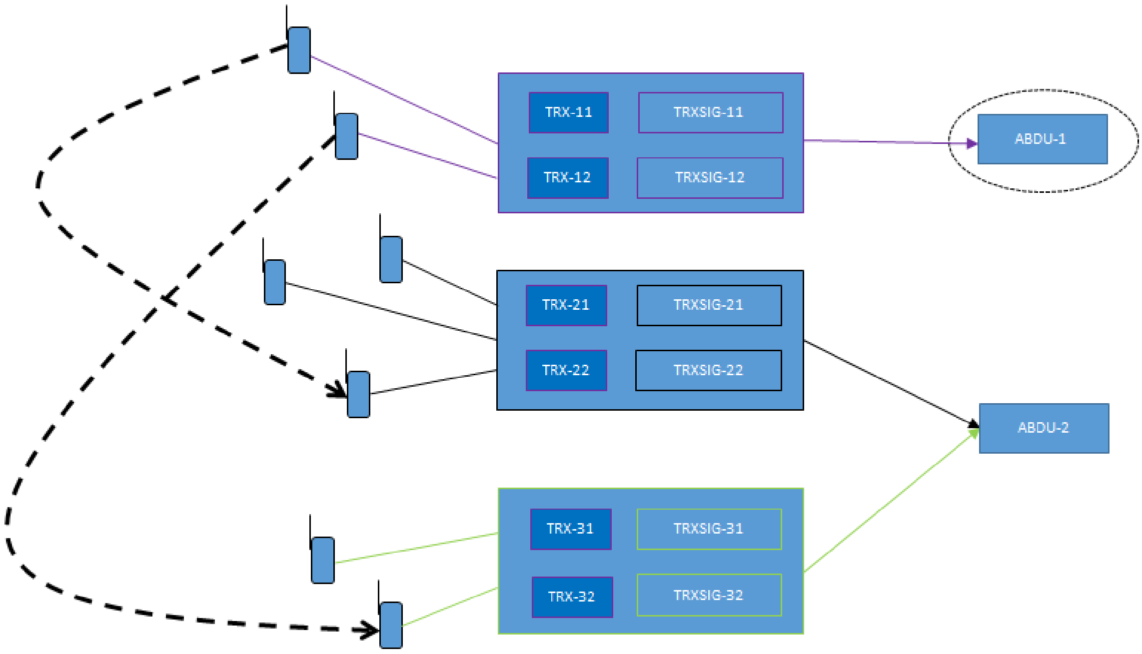

Figure-17: Handover of calls due to ABDU scale-in

There are 2 calls served by ABDU-1 which is being scaled-in. Both are handed over to different radio network served by ABDU-2. In this case too, the forced handovers for TRXs connected to ABDU-1 are triggered when the TRXs are locked one by one. Hand-over follows the existing algorithms in the BSC that analyzes various factors such as BTS loads, traffic volumes and codec types while selecting the target radio network for the handover. Once the handovers are successful, radio network of ABDU-1 is blocked and updated to use another ABDU. This is part of the radio network re-allocation procedure that is described later in this thesis. When all the radio network re-allocation is completed, ABDU-1 VM can be shutdown thereby completing the scale-in operation.

4.3.4 Limitations

This section discusses the limitation in scaling the Abis Interface Data-Plane Unit (ABDU) Virtual Machines (VM). One of the limitations, is the blocking of the radio network, which in turn affects the traffic, although this is done gracefully. If calls cannot be handed over successfully, they are dropped to facilitate completion of the scale-in procedure. This could impact priority calls running on the ABDU and in turn affect the quality of service of the BSC. It is possible to delay the scale-in procedure until the priority calls are terminated, but that could in turn affect the scale-in time for the VM. In the first phase of the Cloud BSC, existing functionality of forced handovers is maintained and that results in calls being dropped if the forced handover is unsuccessful.

4.3.5 Recommendations

This section introduces the recommendations for optimal scaling of Abis Interface Data-Plane Unit (ABDU) Virtual Machines (VM) considering the limitations discussed in previous section. It is recommended that scaling is not autonomous in the first phase. Instead the customer or operator is able to check the configuration and traffic amounts on the ABDU VM before scaling operations are triggered manually. Based on the scaling performance, autonomous scaling triggers could be defined in a subsequent versions of the Cloud BSC.

It is also recommended to perform scale-in, in a graceful and phased manner such that the existing load of the system does not increase due to scale-in handover signalling and traffic disruption is minimal. For the first version of the Cloud BSC, it is recommended to perform that scale-in, in two phases. In the first phase, the ABDU VM for scale-in is selected and "marked" by the operator. Based on this marking, radio resource manager on the BSC ensures that new speech calls and new territory upgrade procedures are not performed for the radio network configured on this ABDU VM. The VM is left in this phase for a pre-defined amount of time, thereby ensuring that traffic load of the VM is reduced gradually. This happens quite naturally when the existing speech calls are released and territory is downgraded due to lower demand. At the same time new calls and territories are not allocated to this VM. At the end of the allotted time period, the user could check the traffic load of the VM and trigger the second phase of scale-in, i.e., forced handover of the remaining speech calls and downgrade of the packet switched territory. If a sufficient amount of time is allowed in phase-1, there may not be a need to trigger the phase-2 of the scale-in operation.

Packet switched territory downgrade procedures are performed during ABDU scale-in, even though ABDU VMs do not serve any packet switched traffic. As mentioned before, this is because the scale-in procedure requires blocking of the BTSs and these BTSs carry both speech and packet data traffic. Only difference is that packet data traffic flows through the Packet Control Unit VMs instead of the ABDU VMs.

4.4 Scaling of Packet Control Unit Virtual Machines

This section describes the various aspects of scaling the Packet Control Unit (PCU) Virtual Machines (VM). PCU VMs are responsible for transporting the packet data user plane traffic between the Base Transceiver Station and the Core Network. It handles both the uplink traffic from BTS towards Core Network and the downlink traffic from Core Network towards the BTS. A group of BTSs are served by a single PCU VM. A radio timeslot on a TRX has a one-to-one mapping to a UDP port on the PCU VM that is reserved during a packet data session. A typical packet switched call involves one or more radio time slots. GSM uses a radio channel access method called Time Division Multiple Access that allows multiple users to share the same frequency channel by dividing the signal into different time slots. These time slots are also called radio time slots and these have a one-to-one mapping with the IP port on the PCU VMs. These ports are reserved for a subscriber on a time shared basis.

4.4.1 Requirements

Just like the BSU and ABDU VMs described in earlier sections, PCU VMs can be subjected to scale-out and scale-in operations.

4.4.2 Scale-out of Packet Control Unit Virtual Machines

This section discusses the scale-out practicalities of a Packet Control Unit (PCU) Virtual Machine (VM). A new PCU VM's processing power can be utilized in an existing BSC configuration in two ways.

1. Configuring the PCU with new radio network configuration, i.e., new Base Transceiver Station (BTS) and Transceiver (TRX).

2. Configuring the PCU to serve existing and active radio network, by moving some of the BTSs from an existing PCU to the new PCU.

The first type of operation has no impact to the ongoing traffic on the BSC, since the new radio network has not started serving active calls. This is also the simplest scale-out case, where new radio network is configured with the new PCU VM and then this radio network is unblocked. It now starts handling active traffic. If the traffic involves data calls, the user plane goes through the newly configured PCU VM.

The second type of operation is not very straightforward since this requires some kind of blocking for the existing radio network, which in turn results in forced handover of the speech calls and downgrading of the packet switched territory. It should be noted that the PCU VM does not handle speech calls. Such calls are handled by the Abis Interface Data-Plane Unit (ABDU) VMs discussed in earlier sections. But the BTSs and TRXs handle both speech calls and packet switched data calls. Hence, blocking of the BTSs inadvertently causes the forced handovers of the circuit switched calls as well. Once the BTSs have been emptied, they can be blocked and their configuration can be updated to utilize the new PCU VM. After the configuration update is successful, BTSs are unblocked and they start serving the traffic. Packet switched territory upgrade procedures and speech calls are established to restore the traffic carrying capacity of the BSC. This is part of the radio network re-allocation procedure that is described later in this thesis. Handover procedure for the speech calls of the impacted radio network, is defined in next section since it’s a common procedure for both scaling-out and scaling-in of PCU VMs.

4.4.3 Scale-in of Packet Control Unit Virtual Machines

This section discusses the scale-in practicalities of a Packet Control Unit (PCU) Virtual Machine (VM). If the data traffic volumes on the BSC are low enough to be sustained by lower number of PCU VMs, some of the existing PCU VMs can be scaled-in. Scaling-in of PCU VMs requires blocking of the radio network configured on this PCU. If there is active data traffic on the scaling-in PCU VMs, those sessions need to be released and the packet switched territory on the PCU has to be downgraded. This territory can then be upgraded when the impacted radio network is moved and unblocked on another PCU VM. Figure 18 shows the operation to be performed.

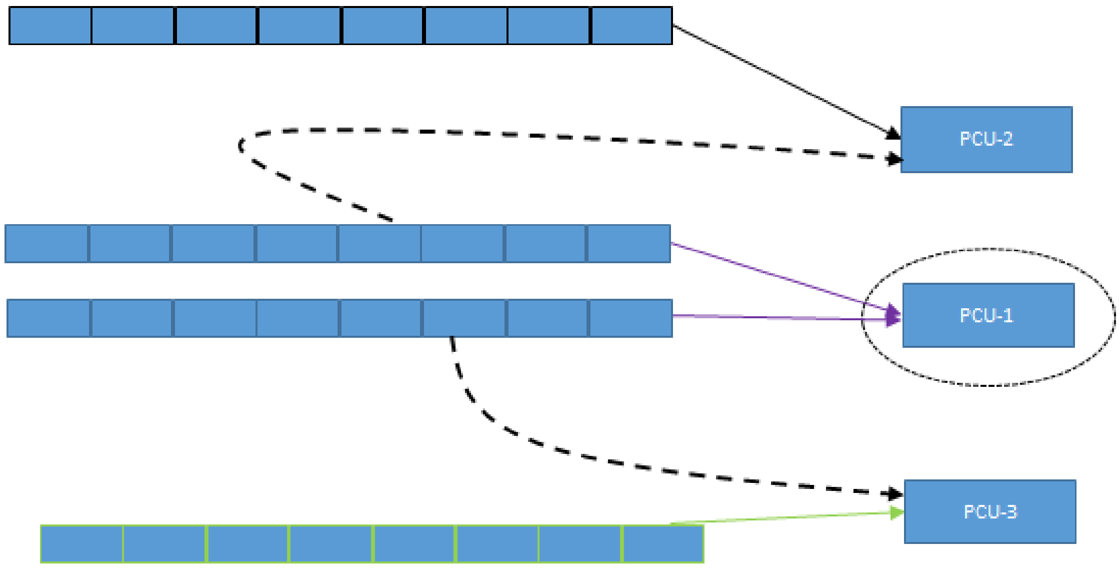

Figure-18: Downgrading and moving packet switched territory due to PCU scale-in

PCU-1 is marked for scale-in and the territory on PCU-1 is split between PCU-2 and PCU-3 when the scaling operation is completed.

4.4.4 Limitations

This section discusses the limitation in scaling the Packet Control Unit (PCU) Virtual Machines (VM). One of the obvious limitation is that radio network blocking has to be performed which in turn affects both speech and data traffic, although this is done gracefully. If speech calls cannot be handed over successfully, they are dropped to facilitate to completion of the scale-in procedure. This could impact priority calls running on the circuit switched part of the radio network connected to the scaling-in PCU. This in turn affects the quality of service of the BSC. It is possible to delay the scale-in procedure until the priority calls are terminated, but that could in turn affect the scale-in time for the VM. In the first phase of the Cloud BSC, existing functionality of forced handovers is maintained and that results in calls being dropped if the forced handover is unsuccessful. Third Generation Partnership Project (3GPP) specified handover sequences are described in Appendix.

Packet switched data calls are not impacted as badly as circuit switched calls, because their quality of service is not as demanding as that of speech calls. Besides the protocol architecture is such that upper protocol layers can be relied on to re-establish the released connections and re-send the lost data.

4.4.5 Recommendations

This section introduces the recommendations for optimal scaling of Packet Control Unit Virtual Machines (VM) considering the limitations discussed in previous section. It is recommended that scaling is not autonomous in the first phase. Instead the customer or operator is able to check the configuration and traffic amounts on the radio network connected to PCU. It is recommended to check the circuit switched traffic on the impacted radio network before scaling operations are triggered manually since speech calls have more demanding quality requirements, while packet data calls' quality requirements are usually "best effort". This is because the applications using packet data services implement their own ways to re-establish a lost packet data session. Based on the scaling performance, autonomous scaling triggers could be defined in a subsequent versions of the Cloud BSC.

It is also recommended that scale-in is performed in a graceful and phased manner such that existing load of the system does not increases due to scale-in handover signalling and traffic disruption is minimal. For the first version of the Cloud BSC, it is recommended to scale-in, in two phases. In the first phase, the PCU VM for scale-in is selected and "marked" by the operator. Based on this marking, radio resource manager on the BSC ensures that new speech calls and new packet switched territory upgrade procedures are not performed for the radio network configured on this PCU VM. The VM is left in this phase for a pre-defined amount of time, thereby ensuring that traffic load of the VM is reduced gradually. This happens quite naturally when the existing speech calls are released and packet switched territory is downgraded due to lower demand. At the same time new calls and packet switched territories are not allocated to this VM. At the end of the allotted time period, the user could check the traffic load of the VM and trigger the second phase of scale-in, i.e., forced handover of the remaining speech calls and downgrade of the packet switched territory. If a sufficient amount of time is allowed in phase-1, there may not be a need to trigger the phase-2 of the scale-in operation.

A point worth noting here is that speech calls are handed over during scale-in even though PCU VMs do not serve any speech traffic. As mentioned before, this is because the scale-in procedure requires blocking of the BTSs and these BTSs carry both speech and packet data traffic. Only difference is that speech traffic flows through the ABDU VMs instead of the PCU VMs.

Figure 19 explains why both speech and packet data calls are impacted when Abis interface Data-Plane Units (ABDU) or PCU VMs are scaled-in.

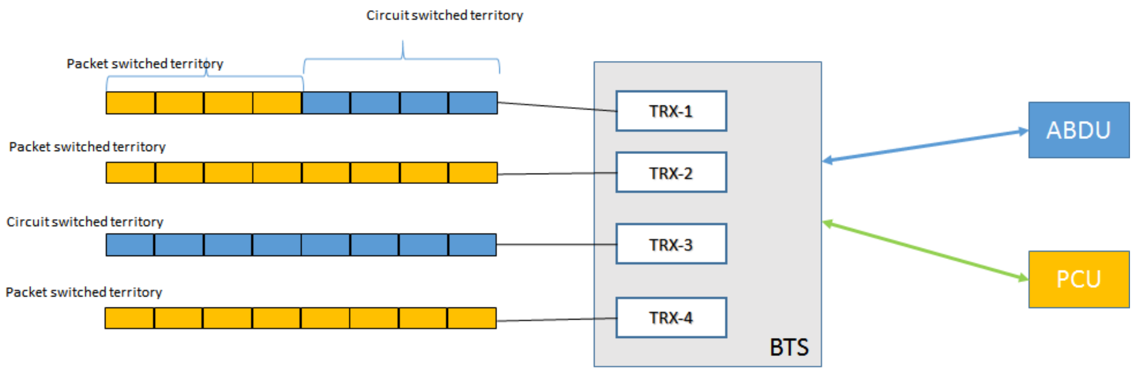

Figure-19: CS call impacts due to PCU scale-in

Both ABDU and PCU scaling operations require the connected BTS and TRXs to be blocked before the VM can be taken out of service. Blocking or locking of the TRXs cause the speech traffic on the TRX to be handed over to another BTS. Blocking also results in the all packet switched territory of the TRX being downgraded. Thus scaling of an ABDU or PCU impacts both the packet and speech traffic on the connected radio network.

4.5 Radio Network Re-allocation

This section discusses the aspects of radio network re-allocation procedures associated with the scaling operations. Once the radio network connected to BSC Signalling Unit (BSU), Abis interface Data-Plane Unit (ABDU) and Packet Control Unit (PCU) VMs is devoid of traffic, the radio network configuration associated with this VM has to be removed and has to be replicated on another VM. This is called a radio network re-allocation procedure. For example, in case of BSU scale-in, the Transceiver (TRX) configuration on the scaling BSU is deleted and then re-created on another BSU VM. However there should be certain criteria for selecting the target BSU on which the TRX can be re-created. If this is done randomly, it could result in uneven traffic and processor loads on BSU VMs leading to VM restarts and severe service impacts to the end user. Similar issues have to be considered when scaling is performed for ABDU and PCU VMs. This section describes the methods of selecting the target VMs to which the radio network configuration can be moved.

4.5.1 BSC Signalling Unit scaling

This section discusses the radio network re-allocation procedures as part of the BSC Signalling Unit (BSU) Virtual Machine (VM) scaling operation. Ideally the Transceiver (TRX) signalling processing is distributed across the BSU VMs as shown in Figure 20.

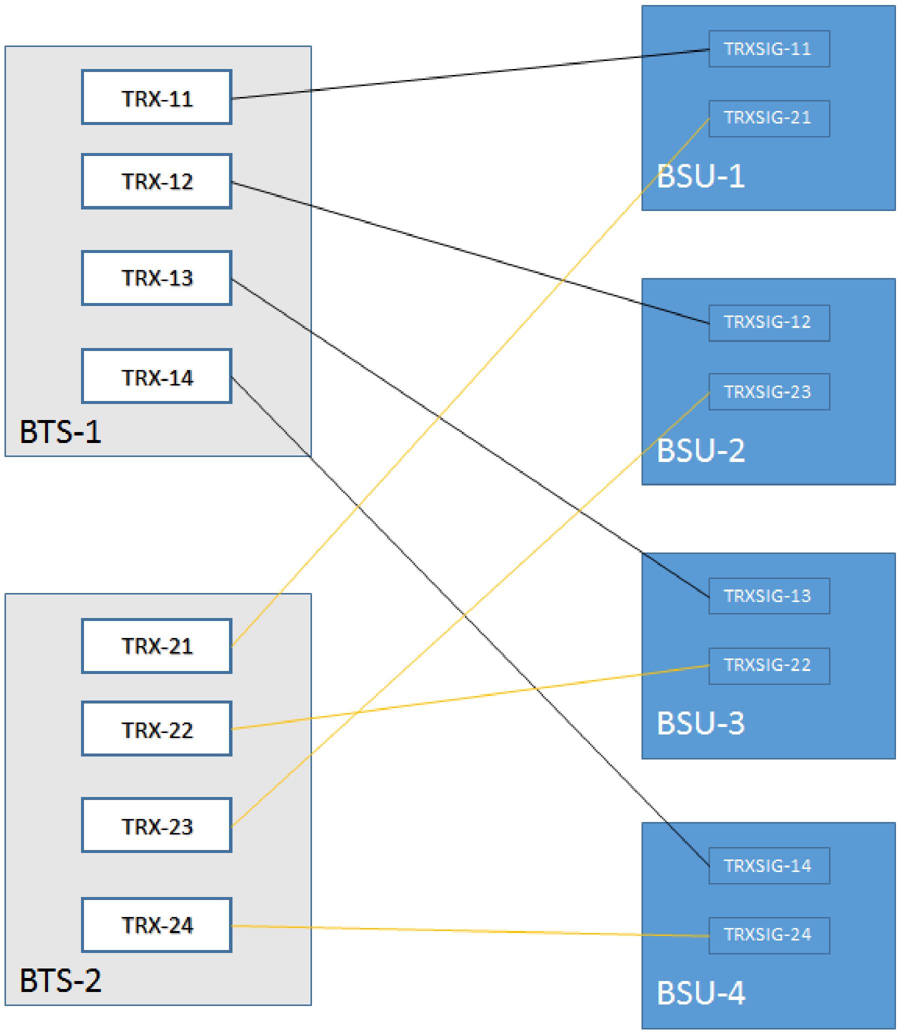

Figure-20: Radio network configuration distributed across BSU VMs

If BSU-1 is scaled-in, it requires moving the interfaces and TRX Signalling (TRXSIG) termination of TRX-11 and TRX-21 from BSU-1 to one of the other BSU units. While selecting the target BSU VM following criteria is desired:

1. VM shall have the lowest number of TRXSIGs.
2. VM shall have lowest processor load.
3. VM shall have lowest traffic load.
4. VM shall have lowest paging load.

It may not be possible to find a single VM that satisfies all the above requirements. For instance a BSU VM may have low number of TRXSIGs, but it may not have the lowest processor or traffic load. For example, consider a radio network configuration where some of the TRXs of the BTS are serving a high cell traffic area such as a shopping mall. If these TRXs are configured on one BSU VM, this VM could be easily loaded during the evenings and weekends. Even though the number of TRXs serving traffic is low, these are heavily loaded, contributing to higher processor and traffic load. Considering all these conditions, a suitable target BSU VM, can be selected using a weighted decision matrix. An example of such a matrix is shown in Table 1.

VMs / **Criteria**	BSU-1	BSU-2	BSU-3	BSU-4
TRX Count	1	1	1	1
Processor Load	2	1	3	1
Traffic Load	1	2	3	2
Paging Load	1	2	4	3

Table-1: Weighted decision matrix for radio network re-allocation during BSU scaling

Here is a description of the criteria in the above matrix (Table 1)

<u>TRX Count</u>

The number of TRXSIGs that are terminated on the BSU.

<u>Processor Load</u>

The virtual Central Processing Unit (CPU) load of the BSU VM.

<u>Traffic Load</u>

The amount of Abis and A-interface signalling traffic on the BSU. This includes the number of active Abis and A-interface processes that are handling the signalling traffic on the BSU.

<u>Paging Load</u>

This is the amount of paging messages pending in the BSU VMs message queue. Paging messages are a big contributor to the VMs traffic handling capacity and heavy paging load can easily be a bottleneck to the VMs performance, often requiring the radio network to be re-configured.

Each BSU unit is ranked against the criteria with rank-1 being the highest rank. The weights for BSU-1 VM is not considered because in this example, BSU-1 is being scaled-in. For other VMs, BSU-2 has the lowest sum of the weights and hence the highest rank. This is now a suitable VM for re-creating the TRXSIG configuration of TRX-11. Once TRXSIG of TRX-11 has been moved to BSU-2, the above decision matrix is applied again to select the next suitable VM for moving the TRXSIG of TRX-21.

4.5.2 Abis Interface Data-Plane Unit Scaling

This section discusses the radio network re-allocation procedures as part of the Abis Interface Data-Plane Unit (ABDU) Virtual Machine (VM) scaling operation. In case of ABDU, the radio network configuration distribution is a bit different than that of BSC Signalling Unit (BSU). In this case, a set of BTSs are connected to an ABDU as shown in Figure 21.

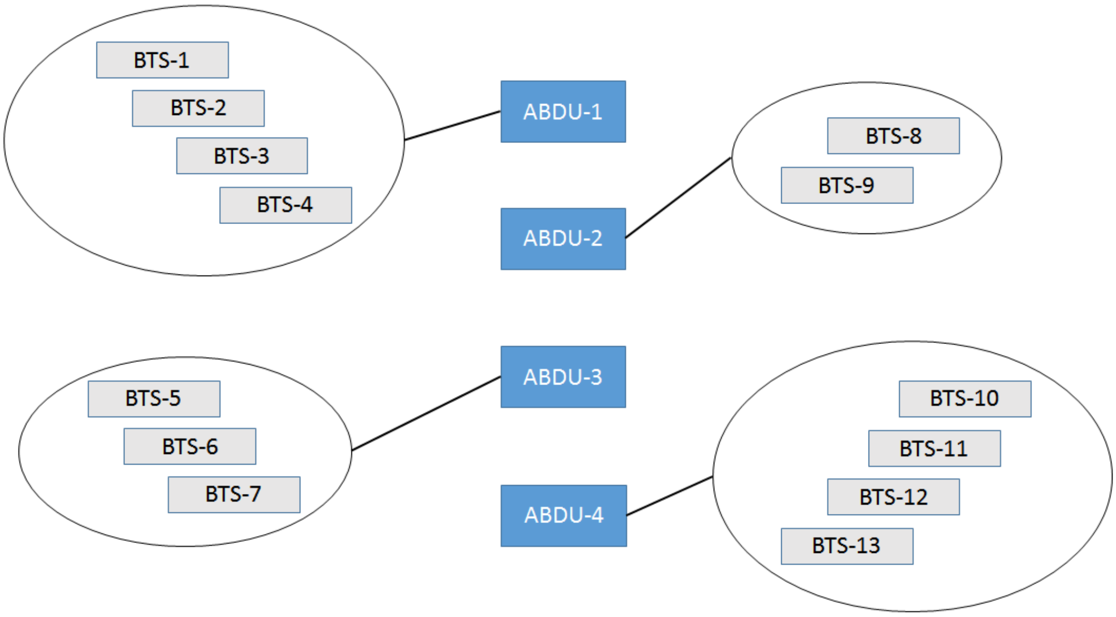

Figure-21: Radio network configuration distributed across ABDU VMs

All the user plane processing related to voice traffic, for Base Transceiver Stations (BTS) 1-4 is handled by ABDU-1. When this VM is scaled-in, all the BTSs handled by ABDU-1 have to be re-allocated to ABDU-2, ABDU-3 and ABDU-4. While selecting the target ABDU VM following criteria is desired:

1. VM shall be connected to the lowest number of BTSs.
2. VM shall have lowest processor load.
3. VM shall have lowest voice traffic load.

It may not be possible to find a single VM that satisfies all the above requirements. For instance an ABDU VM may be connected to few number of BTSs, but it may not have the lowest processor or traffic load. In this case, a suitable target ABDU VM can be selected by using a weighted decision matrix based on the criteria mentioned above. An example of such a matrix is shown in Table 2.

VMs / **Criteria**	ABDU-1	ABDU-2	ABDU-3	ABDU-4
BTS Count	1	2	3	3
Processor Load	2	1	3	1

Voice-Traffic Load	1	2	3	2

Table-2: Weighted decision matrix for radio network re-allocation during ABDU scaling

Here is a description of the criteria in the above matrix (Table 2):

BTS Count

The number of BTSs whose Abis speech user plane traffic is flowing through the ABDU.

Processor Load

The virtual CPU load of the ABDU VM.

Voice-Traffic Load

The amount of speech calls that are active on the ABDU VM.

Each ABDU unit is ranked against the criteria with rank-1 being the highest rank. The weights for ABDU-1 VM is not considered because in this example, ABDU-1 is being scaled-in. For other VMs, ABDU-2 has the lowest sum of the weights and hence the highest rank. This is now a suitable VM for carrying voice related user plane traffic of BTS-1. Once BTS-1 has been connected to ABDU-2, the above decision matrix is applied again to select the next suitable ABDU VM for connecting BTS-2 and so on.

4.5.3 Packet Control Unit Scaling

This section discusses the radio network re-allocation procedures as part of the Packet Control Unit (PCU) Virtual Machine (VM) scaling operation. In case of PCU, the radio network configuration distribution is similar to that of Abis interface Data-Plane Unit (ABDU) as shown in Figure 22.

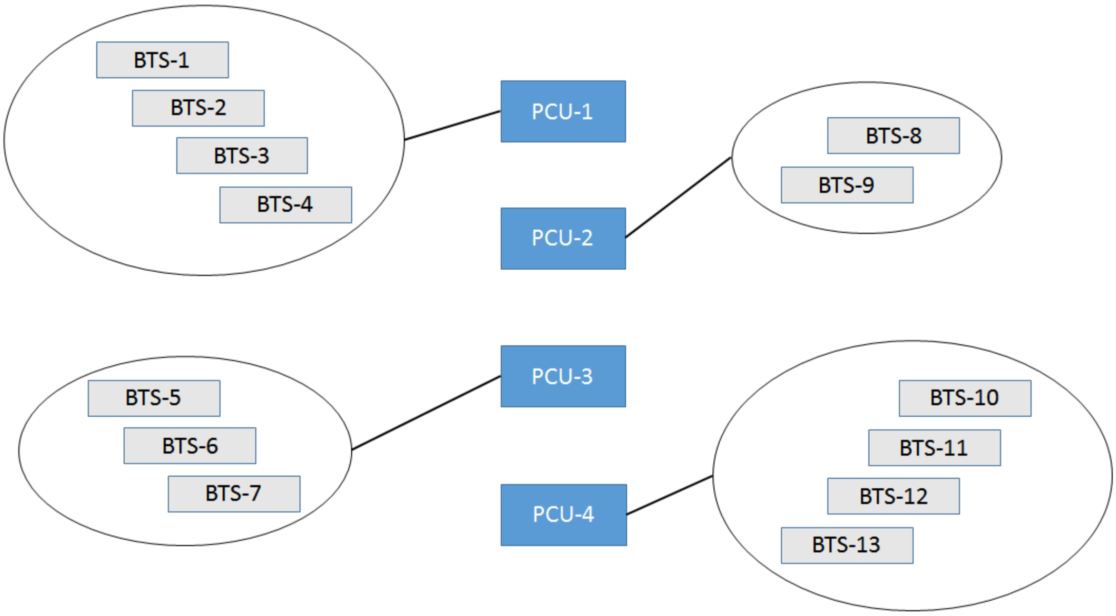

Figure-22: Radio network configuration distributed across PCU VMs

All the user plane processing related to packet data traffic, for BTSs 1-4 is handled by PCU-1. When this VM is scaled-in, all the BTSs handled by PCU-1 have to be re-allocated to PCU-2, PCU-3 and PCU-4. While selecting the target PCU VM following criteria is desired:

1. VM shall be connected to the lowest number of BTSs.
2. VM shall have lowest processor load.
3. VM shall have lowest packet data traffic load.

It may not be possible to find a single VM that satisfies the above requirements. For instance a PCU VM may be connected to few number of BTSs, but it may not be having the lowest processor or traffic load. In this case, a suitable target PCU VM can be selected by using a weighted decision matrix based on the criteria mentioned above. An example of such a matrix is shown in Table 3.

VMs / **Criteria**	PCU-1	PCU-2	PCU-3	PCU-4
BTS Count	1	2	3	3
Processor Load	2	1	3	1

Data-Traffic Load	1	2	3	2

Table-3: Weighted decision matrix for radio network re-allocation during PCU scaling

Here is a description of the criteria in the above matrix (Table 3):

BTS Count
The number of BTSs whose Abis packet data user plane traffic is flowing through the PCU VM.

Processor Load
The virtual CPU load of the PCU VM.

Data-Traffic Load
The amount of packet data calls that are active on the PCU VM.

Each PCU unit is ranked against the criteria with rank-1 being the highest rank. The weights for PCU-1 VM is not considered because in this example, PCU-1 is being scaled-in. For other VMs, PCU-2 has the lowest sum of the weights and hence the highest rank. This is now a suitable VM for carrying packet data user plane traffic of BTS-1. Once BTS-1 has been connected to PCU-2, the above decision matrix is applied again to select the next suitable PCU VM for connecting BTS-2 and so on.

4.5.4 Recommendations

This section discusses the recommendations for optimal radio network re-allocation as part of the scaling operations. Based on the discussion in previous sections, there are several criteria that can be applied while selecting a target Virtual Machine (VM) for radio network re-allocation. Among these criteria, the load related parameters are most dynamic in nature. Hence, basing the decisions on snapshots of such dynamic parameters may not yield optimum results. It is recommended to measure the dynamic parameters, periodically. In other words, the processor and traffic load measurements should be made on a periodic basis and the ranking should be updated accordingly. The other parameters related to TRX and BTS counts can be updated only when there's radio network modifications and there is no need to measure these static parameters on a periodic basis. To add a further level of robustness in VM selection, sampling could be done on the measurements before ranking is performed. For example, the average of 5 consecutive samples could be used for ranking the VMs against the dynamic parameters. Such sampling and measurements also contribute to increasing the load of the system and hence the appropriate number sampling rate should be chosen based on system performance in high volume traffic tests. It may also be beneficial to design configurable parameters for this kind of sampling.

It is also not advisable to have a large number of such criteria for selecting a target VM. Even though it may result in accurate selection of a target VM, the measurement process and associated data structures could impact the system's memory and performance adversely. This is more related to the dynamic parameters such as processor load and traffic load. Quite often these parameters are related in such a way that, if the traffic load increases the processor load increases proportionately. For example the ABDU VMs only process voice packets related to user traffic and an increase of user traffic easily translates to increase of processor load for the ABDU VMs. Hence, it may be beneficial to only measure one of the traffic or processor load parameters for such VMs. But this principle is true only for systems where there is a one-to-one mapping between the virtual CPUs used by ABDU VMs and the physical CPUs configured on the general purpose cloud hardware. This can be explained further with reference to Figure 8 in this thesis. In a standard physical architecture, all CPU cores are used by a single operating system and its applications. However in a virtualized environment, such as the one shown in Figure 8, all CPU cores are virtualized by the Hypervisor and the virtualized CPUs are assigned to VMs based on the requirements of particular applications such as ABDU in the BSC VNF. It is possible to allocate one physical CPU core to a virtual CPU and this is a one-to-one mapping. It is also possible to share a physical CPU core across virtual CPUs and this is called Hyper-Threading. Hypervisor and Hyper-Threading related functionality is not in the scope of this thesis. The relevant point is that CPU load measurement can vary depending on the way physical CPUs are allocated to the virtual CPUs.

To simplify this discussion further, it can be said that virtual CPU load, measured by applications and traffic load measurements are proportional to each other if the virtual

CPU is directly mapped to a physical CPU. If this is not the case, then virtual CPU load and traffic load may not be proportional. Hence, it may be beneficial to just measure the traffic load volumes in former case while it may be beneficial to measure both CPU and traffic loads in the latter case.

In the first phase of Cloud BSC, it is recommended to use a direct one-to-one mapping between the virtual CPUs and the physical CPUs. Hence, it is also recommended to use only traffic load as a dynamic measurement criteria for selecting a target VM. This is in addition to the TRX or BTS counts on the target VM, which has to be considered as a default.

4.6 Scaling of A-interface Data-Plane Unit Virtual Machines

This section describes the various aspects of scaling the A-interface Data-Plane Unit (AIDU) Virtual Machines (VM). AIDU VMs are responsible for transporting the speech related user plane traffic on the A-interface between the Abis interface Data-Plane Unit (ABDU) VMs and the Media Gateway (MGW) in the Core Network. It handles both the uplink traffic from ABDU VM towards Media Gateway and the downlink traffic from Media Gateway towards the ABDU. AIDU VMs have a pool redundancy model, where a set of AIDU VMs share the A-interface user plane traffic within the pool as shown in Figure 23.

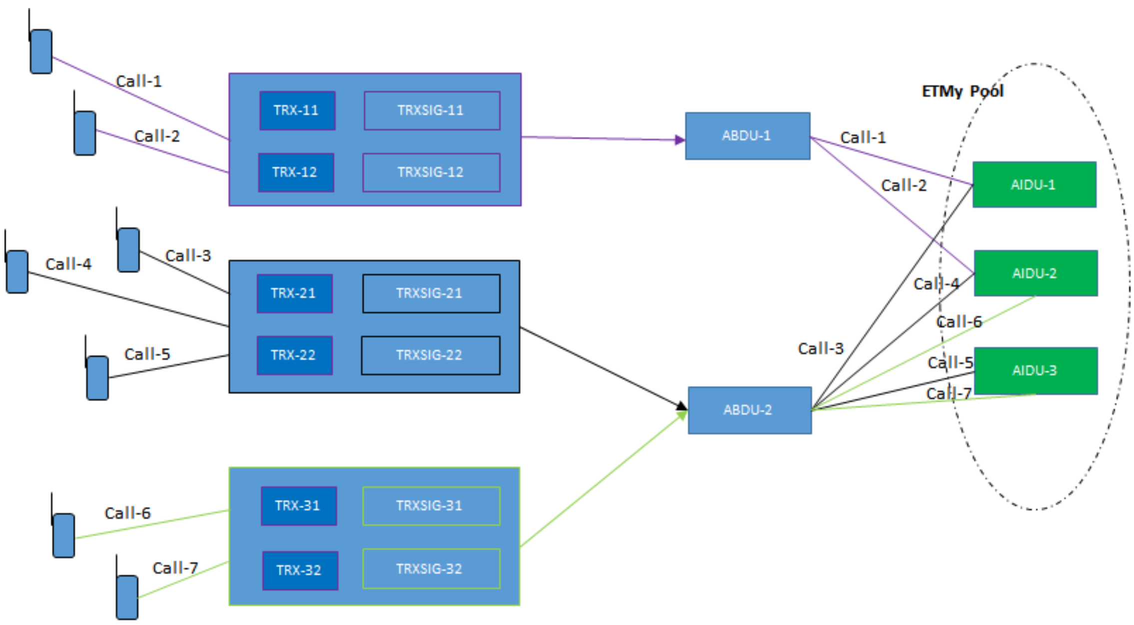

Figure-23: AIDU configured as a pool of resources

Since the AIDU VMs are configured as a pool of resources, the A-interface user plane traffic is distributed between the VMs in the pool, based on the load of the individual VMs. For instance, if there's 7000 speech calls on one AIDU and there are 7200 speech calls on another AIDU VM, BSC distributes new incoming traffic to the first AIDU in order to balance the load of the VMs in the pool. The picture in Figure 23, shows how traffic from the same BTS are distributed across the available AIDU VMs. Call-1 and Call-2 are established through ABDU-1 since its connected to the BTS serving these calls. However Call-1 is established through AIDU-1 and Call-2 is established through AIDU-2 due to load balancing algorithm that distributes the calls among the AIDU VMs.

4.6.1 Requirements

Just like the BSU VMs described in earlier sections, AIDU VMs can be subjected to scale-out and scale-in operations. It should be noted that AIDU VMs are not associated with the radio network and hence radio network re-allocation procedures are not required for AIDU scaling operations. This principle of also applied when designing a new type of handover type for moving the voice calls from one AIDU to another without impacting the Abis side of these voice calls. This approach is discussed in subsequent sections.

4.6.1.1 Scale-out of A-interface Data-Plane Unit Virtual Machines

This section discusses the scale-out practicalities of an A-interface Data-Plane Unit (AIDU) Virtual Machine (VM). If a new AIDU VM is added to the existing pool of AIDU VMs as part of the scale-out operation, the new VM's processing power can be utilized to share the A-interface user plane traffic.

Due to pool based configuration of AIDU VMs, utilizing a new AIDU VM in such a pool is relatively easy because BSC's existing load balancing algorithm starts directing the new traffic automatically towards the new VM, since the new VM has the least load when added to the pool. Once the resource utilization on the new VM is at par with the other VMs in the pool, traffic starts flowing towards the other AIDU VMs as well. This is seen in Figure 24.

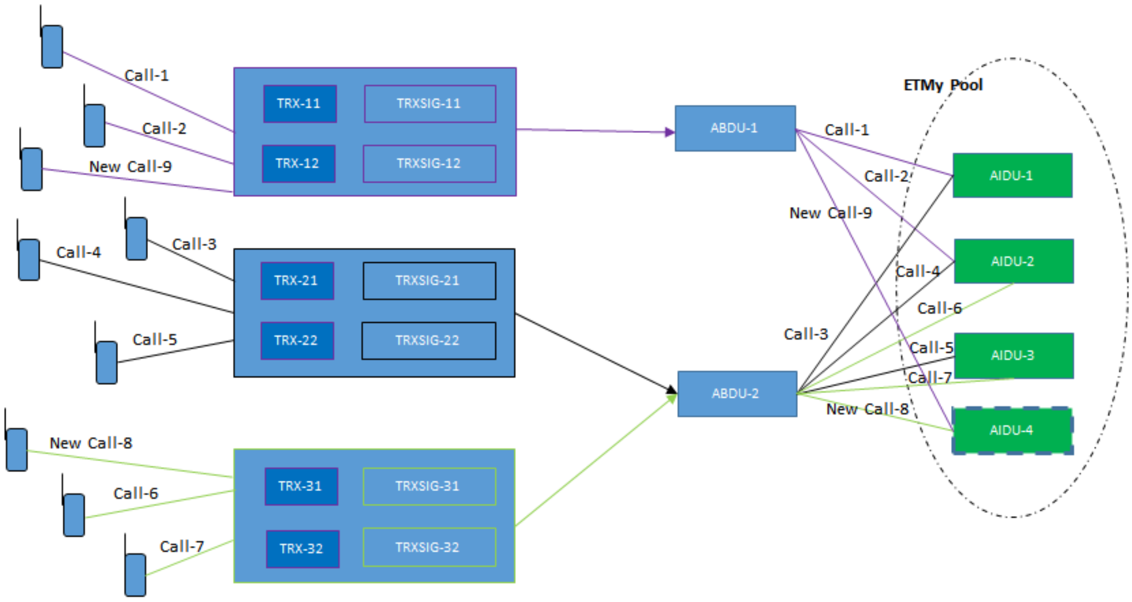

Figure-24: AIDU scale-out and appending to existing AIDU pool

New calls Call-8 and Call-9 are established through ABDU-2 and ABDU-1 respectively and both these calls are routed through AIDU-4 which is the new VM introduced in the AIDU VM pool.

4.6.1.2 Scale-in of A-interface Data-Plane Unit Virtual Machines

This section discusses the scale-in practicalities of an A-interface Data-Plane Unit (AIDU) Virtual Machine (VM). Just like scale-in of other Virtual Machines (VM) discussed in this thesis, AIDU scale-in requires handing over active traffic from the AIDU VM to other AIDU VMs in the pool. Traditional handovers involve a change in the radio parameters associated with the call. In other words, even though only the A-interface user plane traffic flow has to be changed for AIDU scale-in, it will also change the radio timeslot of the subscriber if the traditional handover mechanism was chosen. This includes the usual complexities involved with the radio handover such as selecting a suitable target cell, synchronizing with the new cell and modifying the user plane parameters end-to-end, i.e., the IP addresses and ports of Base Transceiver Station (BTS), Abis interface Data-Plane Units (ABDU) and A-interface Data-Plane Units (AIDU).

An alternative to this approach is to use a new type of handover which involves only updating the A-interface user plane parameters leaving the radio network unchanged.

This is possible by reserving new AIDU resources on another AIDU and updating the ABDU with the end point IP address and port of the selected AIDU. Since AIDU is also communicating with the MGW in the Core Network, signalling message exchange is needed in the A-interface signalling plane to update the new AIDU IP address and port to the MGW. On the A-interface, BSSMAP Internal Handover Required and BSSMAP Internal Handover Command messages are used to facilitate this exchange.

In the subsequent figures (Figures 25, 26 and 27), the sequence for such a handover is explained. With reference to Figure 24, AIDU-1 is being scaled-in and this requires Call-1 and Call-3 to be moved from AIDU-1 to other AIDU VMs in the pool. In the first step to handover Call-1, resources from AIDU-2 are reserved and the new IP address and port are informed to Core Network in BSSMAP Internal Handover Required message. Once this is done, the user plane flow is modified as shown in Figure 25.

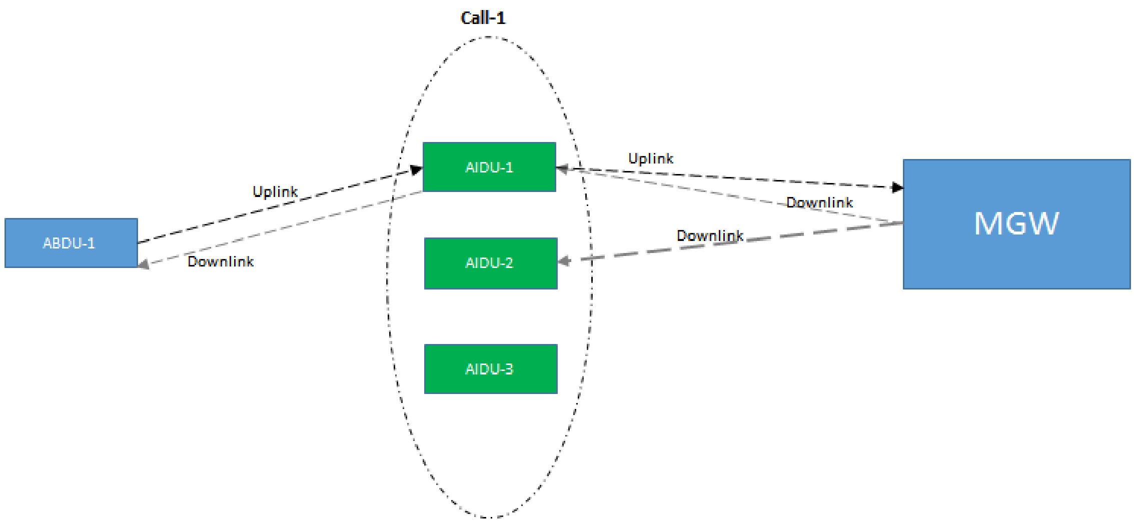

Figure-25: AIDU scale-in handover - Bi-casting in first step

The uplink user plane for Call-1 flows from ABDU-1 to AIDU-1 to MGW. The downlink user plane is bi-casted from MGW to AIDU-1 and AIDU-2. This is done to ensure there is no break in the user plane traffic. In other words, the user does not experience any jitter when the call is moved from AIDU-1 to AIDU-2. In next step, ABDU-1 is updated with the IP address and port for AIDU-2. Subsequently AIDU-2 is updated with the IP address and port of ABDU-1. Once this is done, the uplink user plane starts flowing from ABDU-1 to AIDU-2 to MGW and the downlink gets extended from AIDU-2 to ABDU-1 as seen in Figure 26.

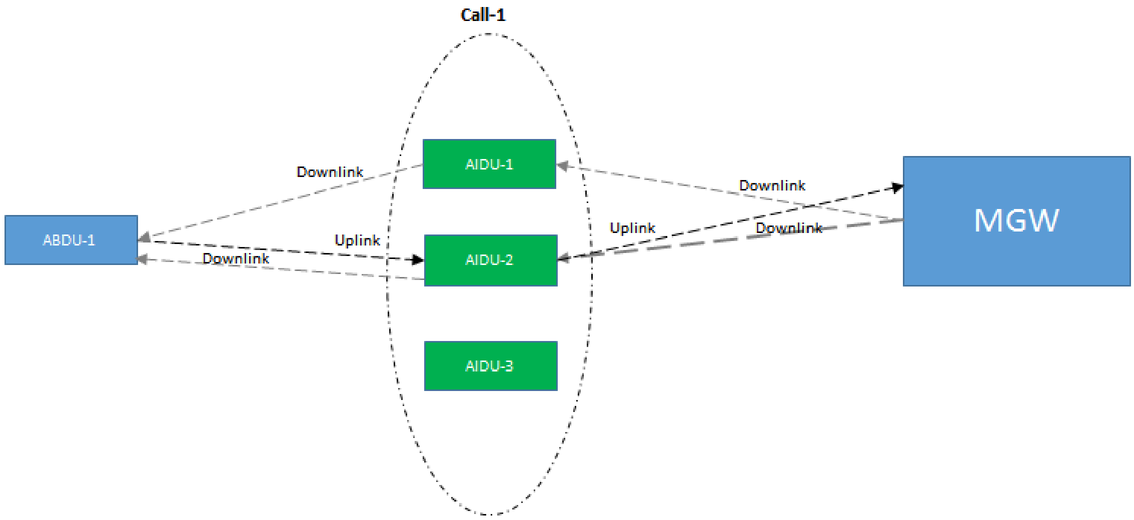

Figure-26: AIDU scale-in handover - Second step

The uplink and downlink paths for the user plane through AIDU-2 is now completed. There are redundant downlink flows from AIDU-1 as well momentarily, but those user plane IP packets are ignored by ABDU-1 since it has been informed in step-2 that downlink traffic is flowing from AIDU-2. In step-3, which is also the final step, handover completion is informed to Media Gateway (MGW) with BSSMAP Handover Complete message. At this point, Media Gateway stops bi-casting the downlink traffic and BSC also releases the resources on AIDU-1. The user plane traffic for call-1 is now flowing as shown in Figure 27.

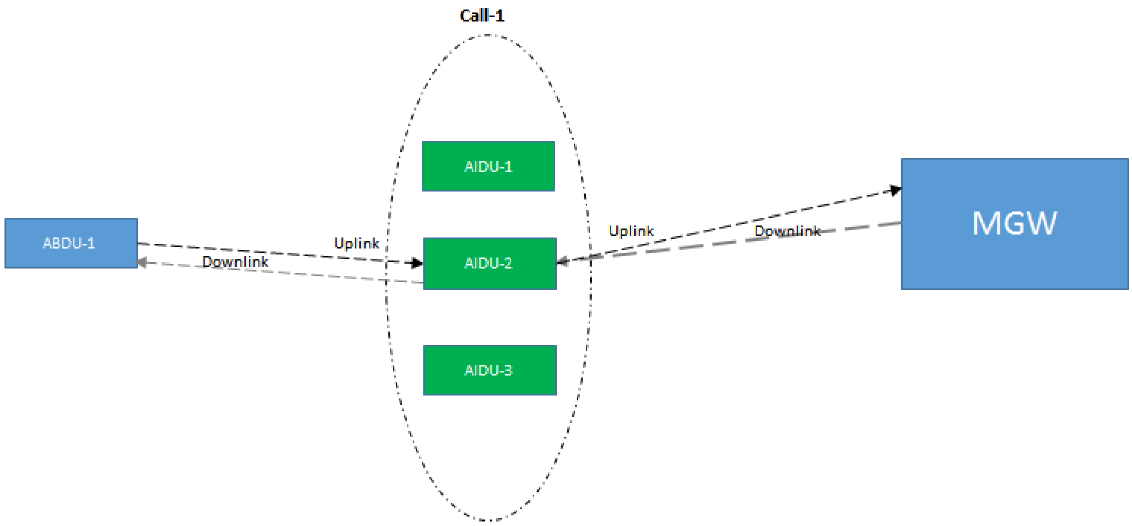

Figure-27: AIDU scale-in handover - Final step

During the entire procedure explained above, radio network remains unchanged for the subscriber since the Abis interface resources – ABDU-1, BTS and TRX are not changed during this handover. Third Generation Partnership Project (3GPP) specified handover sequences are further described in Appendix.

4.6.2 Limitations

This section discusses the limitation in scaling the A-interface Data-Plane Unit (AIDU) Virtual Machines (VM). Although, there are advantages with this kind of "patching" handover, it also poses some limitation with respect to the radio network handovers that could be triggered while the AIDU handover is ongoing. Radio network induced handovers are priority handovers that are typically triggered due to sub-optimal radio conditions of the subscriber, for e.g., while travelling in a car between different cell coverage areas. It is not possible for the BSC to execute two handovers at the same time, and hence it has to reject incoming radio network handover or abort the ongoing AIDU handover. The latter option is not feasible if the handover is in a stage where the IP address between the network elements have been exchanged partially. With such a short signalling negotiation phase between the BSC and Core Network, it seems that aborting the ongoing AIDU handover will not yield any benefits. Hence, rejecting the radio network handover is recommended in such race conditions.

Although repeated rejections of such handovers could possibly cause the call to drop and affect the quality of service of the BSC, it is expected that AIDU change handovers will be completed quite quickly as compared to normal radio handovers. This is because of the limited message exchange involved in this new type of handover. Due to the short time to execute this new handover, it is possible that the subsequent radio handover is executed successfully.

4.6.3 Recommendations

This section introduces the recommendations for optimal scaling of A-interface Data-Plane Unit Virtual Machines (VM) considering the limitations discussed in previous section. It is recommended that scaling is not autonomous in the first phase. Instead the customer or operator is able to check the traffic amounts on the AIDU VM before scaling operations are triggered manually. Based on the scaling performance, autonomous scaling triggers could be defined in a subsequent versions of the Cloud BSC.

It is also recommended that scale-in is performed in a graceful and phased manner such that existing load of the system does not increases due to scale-in handover signalling and traffic is not disrupted. For the first release of the Cloud BSC, it is recommended to scale-in, in two phases. In the first phase, the AIDU VM for scale-in is selected and "marked" by the operator. Based on this marking, A-interface user plane resource manager on the BSC ensures that new speech calls are not established on this AIDU VM. The VM is left in this phase for a pre-defined amount of time, thereby ensuring that traffic load of the VM is reduced gradually. This happens quite naturally when the existing speech calls are released on the AIDU. At the same time new calls are not allocated to this VM. At the end of the allotted time period, the user could check the traffic load of the VM and trigger the second phase of scale-in, i.e., forced handover of the remaining speech calls. This is when the new type of handover described in previous sections, is executed. If a sufficient amount of time is allowed in phase-1, there may not be a need to trigger the phase-2 of the scale-in operation.

Considering that radio network handovers are rejected during ongoing AIDU handovers, it is also recommended to set radio network handover thresholds in a robust manner that allows the handovers to be repeated a few times before the call is dropped. This ensures that the AIDU handover is completed before the next radio network handover is attempted.

5 Autonomous Vs Manual Scaling

This section discusses the various aspects of autonomous and manual scaling operations and the scenarios where one option is better than the other. The scaling procedures discussed in this thesis can be triggered manually by the operator or it could be triggered autonomously by the system. The various trigger points mentioned in previous sections are summarized below:

1. Traffic load of signalling VMs
2. Processor load of the VM
3. Radio network configuration elements on the VM; such as number of Transceivers (TRX)

The Telco Cloud management system is such that, it constantly monitors the radio controller for the parameters above. It is also possible to configure thresholds such that if the average value of the parameters above cross the threshold then system automatically triggers a scale-in or scale-out procedure. This leads to the fact that successful scaling procedures can be executed autonomously only if the thresholds are accurate enough. In the first phase of Cloud BSC, it is not easy to define these thresholds since the architecture of the Telco Cloud is quite different from that of a legacy radio controller. For instance, in legacy systems, a signalling unit may be considered as overloaded if the processor load of the unit is above 70% for a certain period of time. However, in a cloud environment, a signalling VM may indicatively show a load of 70% even during normal operation due to the fact that CPU (Central Processing Unit) instructions have to traverse through Guest Operating System and the Host Operating System before it gets executed on a physical processor. Hence, traditional thresholds cannot necessarily be used for a cloud based radio controller.

Based on the facts, it is recommended to use manual scaling procedures for the first phase of the Cloud BSC. It is still possible to monitor the radio controller and indicate the average values to the operator. But the trigger to scale should come from the operator. Autonomous scaling procedures can be studied further when the performance tests results of the first phase of Cloud BSC are available that provides insights on how the thresholds for the scaling triggers could be defined more accurately.

6 Discussion and Conclusions

This section summarises the study in this thesis related to Elasticity Management procedures for the Base Station Controller. Based on the study performed in this thesis, it is clear that a cloud based second generation radio controller can be subjected to scaling or Elasticity Management procedures. It also discussed how the radio network can be re-allocated to various Virtual Machines after the scaling has been carried out. Furthermore, it is also discussed how handovers are needed to move the traffic between the Virtual Machines during these scaling operations.

It was discussed that BSC Signalling Unit (BSU) Virtual Machines used for terminating the OMSIG (O&M Signalling) and SIGTRAN (Signalling Transport, 1999) links, are not subjected to scaling procedures in the first phase of the Cloud BSC. The limitation comes from the fact that external network elements are dependent on these terminations for the signalling links to work smoothly. It requires further study on how these terminations can be moved away from the signalling Virtual Machines to dedicated Virtual Machines or to external switches, so that all the signalling Virtual Machines are equally available for the scaling procedures. Introducing traffic dispatchers on the A and Abis interface could facilitate this such that Stream Control Transmission Protocol (SCTP) links are terminated on the traffic dispatchers allowing the BSU Virtual Machines to be scaled more freely. Usage of traffic dispatchers is a topic of further study and most probably can be utilized in the next phase of Cloud BSC. For the first phase of Cloud BSC, it is recommended to configure the OMSIG and SIGTRAN links to a subset of the signalling Virtual Machines, so that there are still a few Virtual Machines, without OMSIG and SIGTRAN, available for the scaling procedures.

Another limitation is the shutting down operation of the radio network Transceivers (TRX) during the radio network re-allocation procedures. The TRX has to be reserved (or locked) and then its configuration is deleted. The same TRX is re-created on another Virtual Machine, before it can be taken into use to serve live traffic. Although service impact is minimum due to the fact that calls are handed over to another TRX before deletion, there is still a capacity impact due to shutting down of a TRX temporarily. The entire scaling procedure could also take quite some time to complete due the fact that TRXs are moved one by one. It is a matter of further study, how the current TRX mapping to specific signalling Virtual Machines can be avoided. Instead a central radio network configuration controller could be implemented that allows signalling Virtual Machines to scale-in without affecting the capacity and not requiring the TRXs to be locked when the signalling Virtual Machines are subjected to scaling procedures.

There are other software structures in the Cloud BSC that have been left out of the scope of this thesis, but which also require further study to adapt the BSC to a true cloud environment. For instance Virtual Machine level redundancy has not been discussed, but one could study how the BSC as a whole can be more resilient with Virtualized Networking Function (VNF) level redundancy. Possibly VNF migration options in the platform could be utilized for redundancy purposes. Another topic for further study is the radio network database architecture. The current radio network database uses a file based approach and this poses serious issues in implementing a Virtualized Networking Function (VNF) level redundancy model. It could be further studied how other new and improved database architecture options could be utilized such as a session database which enables seamless VNF migration during HW failure in the cloud platform.

A new type of handover was also discussed as part of the A-interface Data-Plane Unit (AIDU) scale-in procedures. This facilitates quick handover of speech calls to utilize another AIDU Virtual Machine and keeps the Abis side of the call unchanged. This new procedure utilizes Third Generation Partnership Project (3GPP) specified messages on the A-interface to execute the new handover sequence.

With respect to autonomous against manual scaling triggers, it is recommended to focus on manual scaling triggers for the first phase of the Cloud Base Station Controller. In this way the thresholds and performance of the system in the new cloud platform can be studied more thoroughly. In subsequent phases, this study could further be utilized to define accurate thresholds to trigger autonomous scaling.

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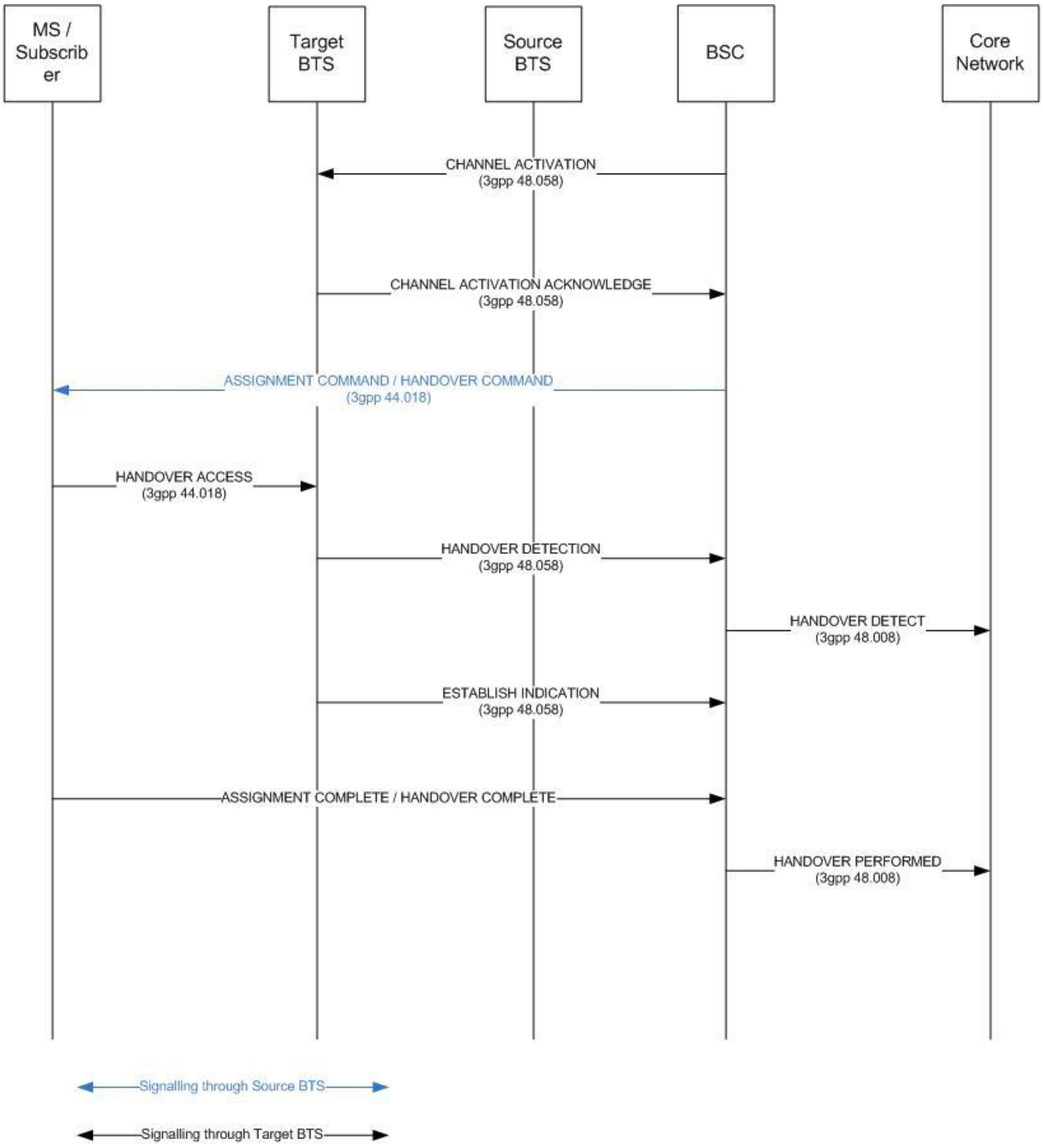
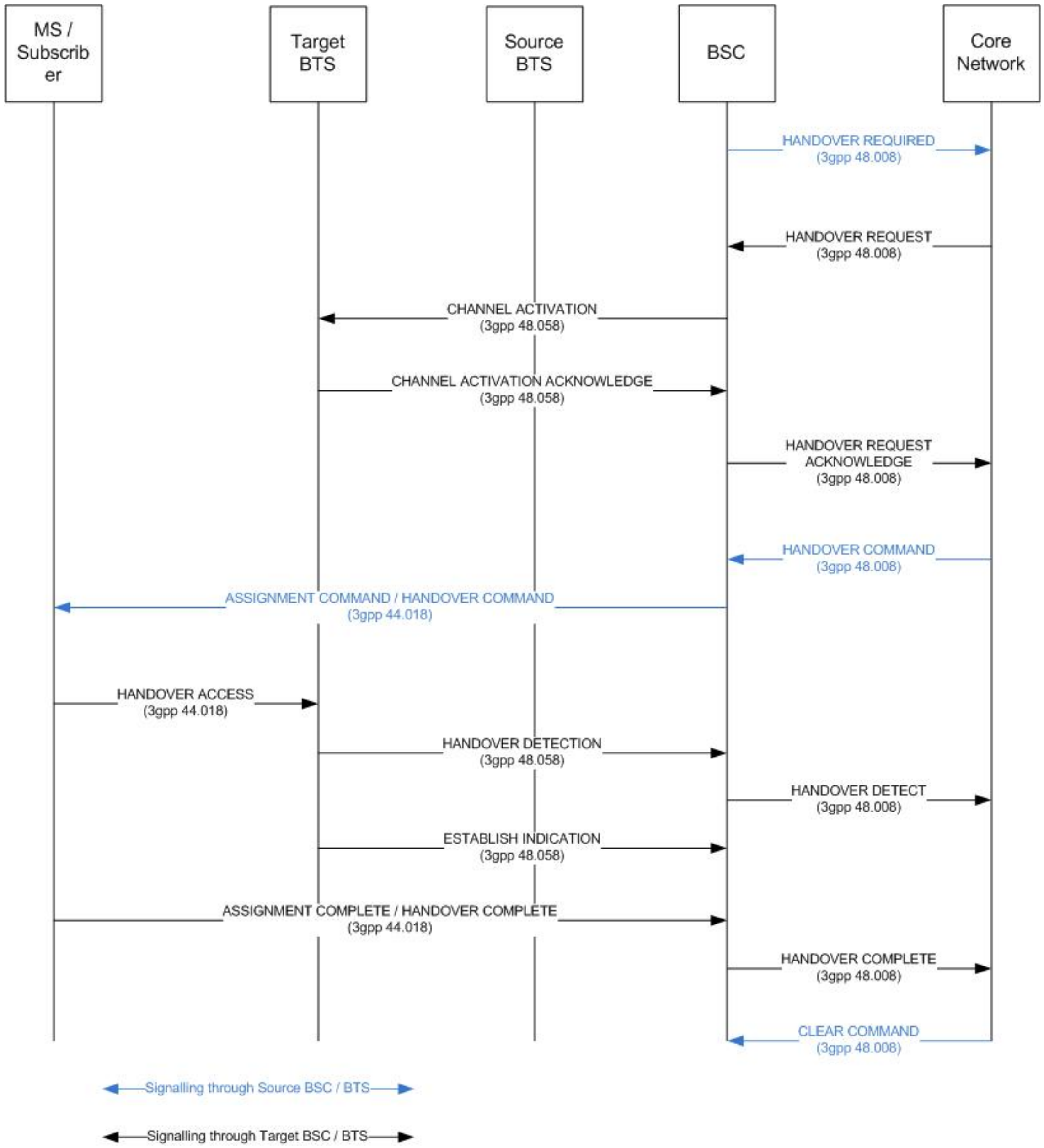
APPENDIX – 1: 3GPP specified GSM Handover Sequences

Signalling sequence between Mobile Station (MS), Base Transceiver Station (BTS), Base Station Controller (BSC) and Core Network (CN) for an Intra-BSC handover is shown below:



Signalling sequence between MS, BTS, BSC and CN for an Inter-BSC handover is shown below. Note that here both the source and target BSCs are the same.



Signalling sequence between MS, BTS, BSC and CN for an MSS assisted Intra-BSC handover is shown below. A-interface signalling shown here is utilized for the new type of handover execution, described for A-interface Data-Plane Unit scale-in operation.